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Please see enclosed the Final Report on Phase I of the Leukemia Study.

Yours truly,

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STUDY OF LEUKEMIA, LYMPHOMA AND OTHER HEMATOLOGIC DISEASES AMONG CLEANUP WORKERS IN UKRAINE FOLLOWING THE CHORNOBYL ACCIDENT

REPORT ON PHASE 1 OF THE STUDY: 1997–1999

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Kiev, Ukraine
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Executive Summary

The accident at the Chornobyl nuclear power plant in Northern Ukraine occurred on April 26, 1986. Eventually, more than 600,000 workers were involved in cleanup operations. These workers are referred to as "liquidators."

The liquidators, particularly those who worked during the first few months of the operation, were exposed to doses of ionizing radiation which, in some cases, were substantial. A study of the risk of leukemia amongst liquidators from the Ukraine as a consequence of such radiation exposure was proposed and designed by working groups of scientists from the Ukrainian Research Center for Radiation Medicine and from the U.S. National Cancer Institute. The protocol for such a study was agreed to officially in 1996.

Because of a number of questions regarding feasibility and design specifics, it was decided first to conduct a feasibility or Phase I study for 18 months. Work started in November 1997 termination has been extended to December 1999. This report describes the results of the Phase I study.

The epidemiologic design, as envisaged in the protocol for Phase II, was for a case-cohort study. A full cohort study was deemed not to be feasible in view of the very large resources which would have been required. The underlying cohort was defined to consist of all liquidators who were recorded on the Chornobyl State Registry, and who were resident at the time of first employment as a liquidator in the oblasts (Dnipropetrovsk, Donetsk, Kiev, Kharkov, Sumskaya) and the city of Kiev.

The Chornobyl State Registry (Section 2) is a computerized database containing records for liquidators and other individuals potentially affected by the accident. Records include identifying information, results of annual medical examinations and, for approximately half of the liquidators, individual estimates of radiation dose. During Phase I, full details of the Registry were compiled,

many registry variables tabulated and available facilities for computerized record linkage investigated. These activities demonstrated that the Registry provided a suitable unbiased source for establishing the cohort, that important variables were generally complete or nearly complete (except for dose), but that new record-linkage techniques would need to be used in a Phase II study.

The study was limited to six geographic areas known to contain large numbers of liquidators (estimated at about 100,000 (89,073)), in order to constrain the resources the study would require (Section 3). However, subsequent investigations revealed that two of the originally-chosen oblasts had inadequate diagnostic material relating to leukemia cases amongst liquidators; a revised set of oblasts was chosen during the Phase I study. It is estimated that from the revised list of oblasts a cohort of approximately 90,000 could be assembled.

Records for the workers in the original oblasts were transferred from the State Registry to form a database in the Research Center for Radiation Medicine (Section 4). It was not feasible during the conduct of Phase I to re-extract the cohort defined by the new set of oblasts, but the success in obtaining records for the original cohort indicates there would be no problem in obtaining a similar database for the new cohort. Distributions of variables from the original cohort database were also tabulated during Phase I.

It was proposed in the original Phase I protocol that cases of leukemia and lymphoma occurring in the cohort would be identified by means of computerized record linkage to medical records maintained at the oblast level, and the feasibility of this approach was also investigated during the Phase I study (Section 5). All cases occurring in the cohort since 1986 and for sometime in the future, i.e., both retrospective and prospective cases, would be identified by this means. An attempt was made to see whether cases among liquidators identified in the oblast of Dnipropetrovsk could be identified in the Chornobyl State Registry. Unfortunately, it appears as though the Registry misses some potential cases of leukemia, lymphoma and related disorders and includes many misdiagnosed cases of leukemia and lymphoma. Therefore, in a Phase II study, linkages would have

to be carried out between the cohort and hematologic and oncologic medical records maintained by individual oblasts and at the Research Center for Radiation Medicine. This would necessitate setting up special medical registries for historical data, i.e., from 1986 to the start of the Phase II study.

A search of hospital records in Dnipropetrovsk for cases of leukemia-related disorders showed that many such cases have been recorded since 1987. None of the cases of liquidators with any of these disorders, however, is registered in the Chornobyl State Registry.

Hematologists at the Research Center for Radiation Medicine have had six orientation meetings with the hemotologists and other responsible personnel in Dnipropetrovsk and several similar meetings have been conducted in each of the other oblasts concerned with the project, since inception of the pilot study. Personnel in all of the oblasts have expressed great interest in, and much enthusiasm for, cooperating with the proposed study.

One critical necessity for any Phase II study would be diagnostic confirmation (Section 6). One very important aspect of the Phase I study was a diagnostic review of the quality of diagnosis in the five oblast hematologic departments and the City of Kiev. This review was based on a sample of individuals from the general population who developed leukemia, related disorders or lymphoma between 1987 and 1998. The objective was to determine the availability of diagnostic material and to investigate the quality of the original diagnoses. A panel of experts from Ukraine, the U.S. and France participated in this review. The results indicated a 90% or greater agreement among members of the expert panel with the previous diagnosis and classification of cases of leukemia on the basis of bone marrow histology in males aged 20-60 at time of diagnosis in the general population of Kiev city and five oblasts. Overall, bone marrow slide recoveries were below 50% for randomly requested cases of leukemia with the lowest recoveries in the early post-Chornobyl years. Slide recoveries were considerably lower for lymphoma. For each time period in most oblasts, however, the recovery of medical records for both leukemia and lymphoma cases generally was appreciably higher.

In addition, a survey was carried out to determine the availability of diagnostic material amongst liquidators with leukemia in four proposed study oblasts as it was believed that more material might be available for liquidators than for the general population and, indeed, this seemed to be the case. Bone marrow slide and medical record recoveries for liquidator cases of leukemia generally were 5-20% higher than they were for comparable male cases in the general population. On the basis of slide and record recoveries for retrospective liquidator cases of leukemia in this small sample the overall potential for retrospective liquidator leukemia case confirmation in the oblasts for the proposed study should be in the range of 80% or greater. The expectations for cases in the immediate post-Chornobyl years, however, are considerably lower.

In order to ascertain potential controls or potential members of a sub-cohort, it was necessary to ascertain how complete follow-up was as represented in the Chornobyl State Registry (Section 7). To investigate this, data from the oblast of Dnipropetrovsk were used. Liquidators who had not appeared for medical examination within the three-year period ending in 1997 were identified in the Oblast Chornobyl Registry (a component of the Chornobyl State Registry), and it was determined that approximately 9% of subjects were "lost to follow-up" in terms of this definition. A sample of 50 such individuals was randomly selected and efforts were made to trace these individuals to determine why they had not returned for medical examination. It was determined that of the 50, six had died, emigrated or otherwise could not be expected to have examinations on file, 35 or 70% could be traced and contacted by other means. Thus, it appears that the Chornobyl Registry at the oblast (and hence state) level is an excellent means for following up cohort members.

Data from cases and controls or sub-cohort members in any Phase II study would be obtained by interview (addressing both dosimetry and epidemiologic issues) and from biological samples, particularly blood. To investigate the feasibility of obtaining interview data, the work in Dnipropetrovsk also included inviting 47 liquidators randomly selected from the oblast registry for interview (Section 8). The response rate amongst those invited to come to a clinic for interview was 66%. It was thought that this response rate would be improved by offering study subjects a more

convenient venue where they could be interviewed, one not involving excessively lengthy travel. It should be noted that the interview content is described in Section 10, and a draft copy is included.

A trial of drawing blood from potential control subjects was also undertaken during Phase I (Section 9). In fieldwork conducted in Dnipropetrovsk, 20 of the interviewed liquidators were approached and all signed a consent form and provided a small venous blood sample for further study. The blood aliquot was then transported to Kiev where its mononuclear cells were successfully separated and cryopreserved. In a similar fashion, mononuclear cells from peripheral blood samples of 27 liquidators with estimated radiation dose exposures in excess of 50 cGY have been cryopreserved.

A key part of any possible future study would, of course, be the estimation of radiation dose for study subjects. Various potential methods were evaluated in the Phase I study (Section 10).

The feasibility of a particular sub-study was also investigated. This was a potential molecular biology study of liquidators who had received high doses, 0.5 gray or greater (Section 11). The objective was to see if 2,500 such individuals could be accumulated from the whole of Ukraine. A total of 1,800 males and females were identified during the Phase I study.

In summary, although the Phase I study could not evaluate the feasibility of every aspect of a possible Phase II study, e.g., it was not possible to carry out pilot work in all the potential study oblasts, the work completed demonstrated no practical barriers to conducting a Phase II study. A cohort of adequate size with essentially complete data (except for doses) could be assembled from the Chornobyl State Registry and identification of cases would seem likely to be essentially complete. Diagnostic confirmation, and the availability of diagnostic data for liquidators, again, seems to be of a high quality. Follow-up by means of the Chornobyl State Registry is also very complete, with only a very small loss to follow-up. The response rate to invitations for interview amongst potential controls/sub-cohort members, though estimated in the feasibility study at 66%, probably could be increased by providing more convenient places for interview or other

inducements. Acceptance of blood drawing was high, 100%, among the 66% interviewed, and there seemed to be no problems in transporting samples to Kiev for processing and storage.

Extensive work was carried out on dosimetry, and the resources at the Research Center for Radiation Medicine in Kiev are generally excellent. The method chosen for dosimetry would seem to be adequate to provide reasonable power for a study, allowing for a reasonable degree of measurement error in dosimetry: an estimation of power was made for Phase II in the 1996 protocol; re-estimation was not part of the Phase I study, but has been conducted separately (G.R. Howe, personal communication).

The pilot study did not address the scientific justification for carrying out a Phase II study; this will be the subject of a formal proposal if it is decided to proceed with a Phase II study. As well as demonstrating feasibility, the Phase I study has provided invaluable experience for Ukrainian scientists who have been involved and would have primary responsibility for the conduct of the Phase II study. It has also demonstrated the practical success of the collaboration which has developed among those Ukrainian scientists, the staff from NCI and the collaborators from Columbia University, a collaboration which would, presumably, continue if a Phase II study were to be proposed and funded.

1. Introduction

The accident at the Chornobyl nuclear power plant in northern Ukraine occurred on April 26, 1986. Large amounts of radioactive material were released into the area immediately surrounding the plant, and into the atmosphere from which they were deposited across large areas of Ukraine, Belarus and Russia and, to a lesser extent, in other states and countries.

The cleanup of the effects of the accident started almost immediately. In total, eventually some 600,000 cleanup workers (subsequently referred to as "liquidators") participated in cleanup activities starting in 1986. Liquidators came from a number of states in the former Soviet Union, consisted

mainly of men, and included both professional nuclear workers, a large number of army conscripts and various other groups. Clean up work was concentrated in the power plant itself, and in the 30 km zone around the plant, which was evacuated starting several days after the accident. Today the 30 km zone remains evacuated of its civilian population, though other units of the power plant itself still function to generate power.

Under a bi-national agreement between the Soviet Union and the United States, it was agreed that the U.S. would collaborate with the Soviet Union in various areas relating to nuclear power, including studying the health consequences of the Chornobyl accident. One of the proposed studies was of leukemia risks in liquidators from Ukraine. Leukemia is one of the most radiation sensitive cancers, and has a relatively short latent period of about two years. Therefore, one would expect leukemia to act as a potential marker for increased cancer risk among the liquidators if such were to occur.

Following several years of consultation between staff and consultants from the U.S. National Cancer Institute and scientists at the Research Center for Radiation Medicine, Ukraine, a protocol was developed for an epidemiologic study of leukemia amongst Ukrainian liquidators. However, because it was not clear at the time the protocol was being developed that some important aspects of the proposed study were feasible, it was decided to mount a pilot study to determine feasibility. The pilot study was also planned to evaluate several alternative approaches to various aspects of the study, such as the choice of an appropriate dosimetry method. The pilot study, referred to as Phase I, was funded by the U.S. National Cancer Institute, the Department of Energy and the Institute of Nuclear Protection and Safety (IPSN), and was initiated in November 1997. The study was conducted by scientists at the Research Center for Radiation Medicine, under the direction of Academician A.Y. Romanenko, in collaboration with staff and consultants from the U.S. NCI.

This report presents the results of the Phase I study together with an evaluation of the feasibility of a more complete study, the proposed Phase II study.

Phase I was designed as a series of tasks, mainly in the areas of epidemiology, hematology, dosimetry and administrative aspects. For the sake of clarity, this report is organized in eleven sections (Sections 2-11) each of which deals with a particular component which would be involved in a full Phase II epidemiologic study. These sections follow the logical sequence which would be involved in such a study, and the various tasks relating to each section are grouped in that section without being specifically identified as "tasks." The task numbers covered in a particular section are given at the start of that section, and Appendix 1 provides a complete list of tasks in numerical order with indications of the paragraphs in the protocol where they were defined..

2. The Chornobyl State Registry

[Tasks 1, 2 and 3]

2.1 Introduction

The Registry would be the basis for choosing the cohort and following up members of the cohort in various ways. Its identifying information also could be used to link cohort records to other files such as hematologic department records and the Cancer Registry. In Phase I, a detailed description of the Registry was obtained, tabulations of essential variables produced and linkage facilities evaluated.

2.2 Description of the Registry

The Chornobyl Registry was designed by the Soviet government shortly after the accident in 1986 to aid in the social, economic, and health maintenance of those who suffered from the Chornobyl Nuclear Power Plant (CNPP) accident. The Ukrainian segment of the Registry is established in Ukrainian law as the State Registry of Ukraine and is managed by the Ministry of Health with support from the Ministry of Ukraine of Emergencies and Affairs of Population Protection from the Consequences of the Chornobyl Catastrophe. Within the Ministry of Health the Registry is managed by the Center of Information Technologies and National Registry.

Below the State Registry are component registries at the level of raions, oblasts, the Crimean Republic, and the cities of Kiev and Sevastopol. Information flows from providers at all levels (e.g., polyclinics at the raion level, oblast dispensaries, etc.) through these source registries via telecommunication facilities to the State Registry in Kiev.

Registration of the individual cleanup worker is based on several documents that supported his service in the work zone, his passport and, after 1991, a Victims Certificate that is given to each cleanup worker by the Oblast State administration. By regulation, cleanup workers are expected to be examined yearly. The Registry contains information on all classes of sufferers of the Chornobyl accident: cleanup workers; evacuees from the 30 km zone around the CNPP; residents of the territory contaminated by fallout from the accident; and the children of these three affected groups. The State

Registry holds records on more than 725,000 individuals, about 200,000 of whom are cleanup workers.

The Registry is an information system with the capacity for creating longitudinal records of individuals with respect to:

- identifiers
- residence history (beginning at the time of registration)
- occupational history (including just prior to assignment to the Chornobyl work area and at the time of registration as a cleanup worker)
- results of individual medical examinations since registration (systems, diagnoses, disabilities, etc in ICD 9)
- Chornobyl work history
  - fnction performed
  - dates of service
  - external radiation dose (official record)
  - thyroid dose
- registration as a cleanup worker

The Registry is a closely held confidential file for official use. Access is controlled by the Ministry of Health. It can be searched by name or characteristic, e.g., cleanup worker, residence, dose, etc.

Table A2.1 (Appendix 2) shows the variables contained in the State Registry and their description.

2.3 Distribution of Variables in the Registry

The volume of tabulation requests to the Registry was markedly affected by a scarcity of computer equipment of sufficient power in the early months of the project. With the provision of equipment needed by the Registry to support the project it became possible to tabulate most of the characteristics of interest, i.e.:

- Type of registrant (several types of adult registrants, and children) by oblast of residence, January, 1998.
- Cleanup workers by year of birth, year of service in cleanup work, and sex.
- Cleanup workers by oblast of residence, year of service, and sex.
- Cleanup workers by reported official dose and year of service.
- Dniepropetrovsk cleanup workers by year since last medical examination.
- Cleanup workers in the six oblasts initially selected for Phase II, by year of service.

Tables A2.2–4 (Appendix 2) contain three of these tables for illustrative purposes:

Table A2.2 Cleanup workers by year of birth, year of service, and sex

Table A2.3 Cleanup workers by reported official external dose and year of service

Table A2.4 Cleanup workers by year of service and year of registration.

2.4 Record-Linkage Facilities

Automated record linkage occurs throughout the Registry system, especially in updating existing files with new information. Exact matches are required and mismatches are dealt with manually. Characteristics used in matching within the system are: given name, surname, patronymic, date of birth (day, month, year), and registration number. Linkage with external files was performed several times during Phase I, for example, with the Dnipropetrovsk Cancer Registry and hematology records (Section 5). The programs used may need to be improved for Phase II; e.g., probabilistic matching procedures are now available.

Professor Howe held a one-week workshop on probabilistic record linkage in Kiev that was well attended by project staff, Registry staff, and others with similar needs. He also provided some software for linking external files to the Registry which will need further modification.

3. Selection of Study Oblasts

3.1 Introduction

A Phase II study would have to be limited in geographic area to keep study resource requirements at a reasonable level. During Phase I, five oblasts and Kiev city were initially selected and evaluated, particularly with respect to the availability of diagnostic material for retrospective cases among the liquidators. The latter material was deemed inadequate in two of the oblalsts (see below) and substitutions were made.

3.2 Selection and Evaluation of Study Oblasts

The criteria used for choosing study areas were: a large population of liquidators, accessibility to Kiev City, anticipated cooperation from the area's medical authorities and availability of diagnostic material for retrospective cases. The initially selected study areas were the oblasts of Dnipropetrovsk, Donetsk, Sumskaya, Kiev, Kharkov and Kiev City.

In preparing for the diagnostic review it was found that the Donetsk and Sumskaya oblasts could not meet the quality control requirements of the project with respect to the documentation of diagnoses of interest. Further investigation of other oblasts resulted in the substitution of Cherkasy and Chernigiv oblasts, cleanup workers in which have not yet been added to the cohort. The principal reasons for selection of these oblasts are their proximities to Kiev, the extremely high levels of cooperation by their hematologists, and the expectation of better recovery of clinical records and histologic materials for the liquidators with leukemia in these oblasts as compared to either Donetsk or Sumskaya.

4. Selection of Cohort and Formation of Cohort Database

[Task 4]

4.1 Introduction

During Phase I a cohort based on the initially-selected oblasts was formed by extracting the relevant records from the Chornobyl State Registry. When new study oblasts were selected (Section 3), the

entire new cohort was not formed during Phase I, but the process should be identical to formation of the initial cohort.

4.2 Formation of Cohort

Review of the selection criteria suggested that a cohort of about 98,500 could be assembled. During the wait for computer equipment needed by both the Registry and the Data Coordinating Center for the project, attention turned to the database that would be needed to establish the cohort and to support the study in Phase II. Consideration was given to its structure, management, codes, data input forms, and software needs. In addition, provision was made for separate databases for the dosimetry operations and for hematology together with the means for data-transfer to the main database in the DCC.

In view of the dependence of the database, both initially and continuing, on the Chornobyl Registry, it was decided that the Registry would maintain a duplicate file for the cohort. This would facilitate the update of information in the database for the study as well as furnish the Registry with feedback from study operations if required.

In 1998, both the dosimetry laboratory and the Epidemiology Laboratory were moved, the Epidemiology Laboratory to space within the Chornobyl Registry. This physical move was accompanied by the assumption of responsibility by the Registry for the Laboratory environment and the linkage of computer facilities between the Laboratory and the Registry.

The close connection between the Epidemiology Laboratory and the Registry and the availability of the necessary computer equipment, made it possible to begin selecting the cohort and establishing the necessary files within the Epidemiology Laboratory. The initial selection of the cohort from the 6 original oblasts produced a file of 100,000 subjects with composite identifying numbers consisting of the oblast code and the unique identifying number assigned the individual within each oblast. The information captured for each member of the cohort consists of:

- Registration Information (including year of birth)
- Address
- Dose
- Chronic Diseases Detected before 26 April, 1986, or before entering the working zone.
- [1]Talon (Diseases detected during annual examinations)
- Presence in Isolation Zones in 1986, 1987-1990 (including year of service)
- Presence in Isolation Zones at the Time of the Accident
- Dose (rads) (total offical dose)

Tables A4.1-A4.4 (Appendix 2) show the completeness of selected variables for the cohort, and distributions by age group, year, started work at Chornobyl by official dose and oblast of residence.

5. Identification of Cases

[Tasks 20, 21, 23, 24)

5.1 Introduction

In order to assess the feasibility of identifying cases in a Phase II study, several tasks were performed. These were designed to assess the utility of the Chornobyl State Registry for identifying cases (Sections 5.2 & 5.3), to evaluate the oblast hematology services as the primary source of information for liquidator leukemias and lymphomas 1987-1997 (Section 5.4), to learn the type of diagnostic materials that would be available for review (Section 5.5), to investigate issues regarding leukemia-related disorders (Section 5.6) and the establishment of contact with hematologists in the study oblasts (Section 5.7).

[1]Talon is the card used to record codes for diseases detected during the annual medical examination.

5.2 Identifying Leukemia and Lymphoma Cases Occurring in Dnipropetrovsk Between 1987 and 1997

The medical records of the Cancer Registry, the oblast hematology department and the Department for Support of Medical Victims in Dnipropetrovsk and the Research Center for Radiation Medicine (RCRM) in Kiev were searched for cases of leukemia and lymphoma which had occurred among men from Dnipropetrovsk, ages 20-60, during the years 1987-97. The medical records of all patients with either leukemia or lymphoma at the time of the accident contained information as to whether they were liquidators or evacuees.

5.3 Linking Leukemias/Lymphomas to Registry

Twelve cases were identified as clean-up workers in Dnipropetrovsk with leukemia as noted in the search in section 5.2 above. Eight of the 12 were registered in the Chornobyl State Registry (Table A5.1, Appendix 2). One of the 4 cases not registered was a verified case of leukemia. The other three cases which had originated from the Cancer Registry were subsequently shown to be leukemia-related disorders rather than leukemia. Over half of the cases registered as leukemia in the Chornobyl State Registry had been miscoded (Table A5.1, Appendix 2). All cases of lymphoma identified in Dnipropetrovsk clean-up workers from the same sources as the leukemia cases were registered in the Chornobyl State Registry but one of the Cancer Registry cases, however, probably is a case of leukemia. About two thirds of the cases registered as lymphoma in the Chornobyl State Registry were miscoded (Table A5.1, Appendix 2).

5.4 Evaluation of Oblast Hematology Services as the Primary Source of Information for Liquidator Leukemias and Lymphomas

The results of the cross-search for information obtained from the oblast of Dnipropetrovsk and the Center for Radiation Medicine indicates that the Chornobyl State Registry is not a reliable source for the accurate identification of cases of leukemia and/or lymphoma which may have occurred in the Chornobyl clean-up workers in Ukraine. The pilot work indicates that information on retrospective cases of leukemia and lymphoma which occurred in the clean-up workers of any

particular oblast would have to be obtained directly from oblast sources (Tumor registry, Department of Hematology and the Department for Medical Support of Chornobyl Victims).

5.5 Availability of Diagnostic Materials and Organization of a Diagnostic Review

Hematology Department investigations in several hospitals in Dnipropetrovsk indicated that medical records, bone marrow smears and tissue sections from many patients with leukemia and lymphoma had been retained for periods of 8-10 years or more. The tissue and bone marrow preparations generally were in a good state of preservation. Medical diagnoses were organized so that there was easy access to the medical record.

It appeared from these investigations that a retrospective hematology review of medical records for adult males with leukemia, lymphoma and related disorders over a span of the last 8-10 years was feasible. It was proposed that hospital personnel in Kiev in conjunction with hematology and epidemiology staff members of the RCRM in Kiev would identify a random sample of representative cases which occurred during predetermined periods of time. Abstracted medical records and available tissue slides then would be sent to Kiev for review by an international group of expert hematologists.

5.6 Meetings with Hematologists, Oncologists, and Pathologists

It was proposed in the protocol that a one-day orientation meeting be held in Kiev with key hematologists from the six study areas proposed for the study. This meeting was not held as an early decision was made to concentrate pilot project efforts in Dnipropetrovsk. However, many general discussions between members of the hematology staff in Kiev and the hematologists and oncologists in other oblasts have been conducted over the course of the past two years. The responsible physicians and administrators in those areas now understand the general structure of the program and have expressed their willingness to participate in the future. It is appreciated that their cooperation is essential if pretreatment blood is to be obtained for special studies in Kiev from liquidators who develop hematologic disorders of interest in the future. An orientation meeting will be held in Kiev

with key oblast personnel from the oblasts selected for the project at the initiation of any Phase II project.

A total of six meetings have been held with the responsible physicians and other personnel in Dnipropetrovsk. Emphasis was placed on the conduct of interviews, informed consent, and the drawing, processing and shipping of blood samples to Kiev.

6. Confirmation of Diagnoses

[Task 22]

Following identification of cases in a Phase II study, it will be necessary to confirm the accuracy of the corresponding diagnoses. Perhaps the most important hematology responsibility during Phase I has been that of determining the extent to which retrospective cases of leukemia, lymphoma and related disorders can be verified histologically and through medical records. In order to make these determinations the medical records and histological slides for 20 cases for each of eight specific hematological disorders (Table A6.1, Appendix 2) were requested to be randomly selected from hospital rosters in Kiev city and each of five outlying oblasts between the years 1987 & 1998. Case materials were requested as equitably as was possible for three specific time periods (1987-1990, 1991-1994, 1995-1998). Investigation of specific liquidator slides and records was not attempted since the number of cases on record was not large enough to satisfy the need for diversification of cases by time and type of disease in their review. Also the general opinion had been expressed that liquidator cases were managed in the same manner as were cases in the general public so that the latter could serve as surrogates for the liquidators.

In January of 1999 a panel of expert hematologists (two from Ukraine, two from U.S.A. and one from France) completed a bone marrow slide and case record review for about 100 cases of leukemia, lymphoma and related disorders which had been collected in accord with the method described above. Members of the panel first concluded that diagnostic criteria and systems of classification for the hematological diseases being evaluated were essentially the same for the three

countries represented by members of the review panel. The most important results of the hematology review indicated that for leukemia cases with bone marrow slides the rates of disease confirmation and agreement with disease classification were in the range of 90% or better among the members of the panel and with the original diagnoses (Table 6.1). The results for lymphoma were similar for cases with tumor tissue slides (Table 6.2). Rates of confirmation for the leukemia-related disorders were about 50% for myelodysplasia, about 70% for multiple myeloma, but less than 15% for cases of myelofibrosis, hypoplastic anemia and aplastic anemia (Table 6.1). In general, slide quality was quite good. The results of the review also showed that case record recoveries for all hematological disorders investigated usually were 10 to 20% greater than for histological materials for each time period (Tables A6.2 and A6.3, Appendix 2). Patient medical records invariably included a report of the results of pretreatment peripheral blood and bone marrow or tissue biopsy studies. Some problems in the differentiation between myelodysplasia and acute leukemia were encountered but these differences were not unexpected.

Table 6.1
Consensus Results of Review of Leukemia, Myeloma and Related Disorders by Expert Panel, Kiev, January 1999. (Task #22)

Diagnosis	Total Cases		Cases With Slides	
	# Confirmed /Total #	% Confirmed	# Confirmed /Total #	% Confirmed
Chronic Lymphatic leukemia	10/72	83	7/7	100
Acute Leukemia [2]	27/31	87	25/28	89
Chronic myelogenous leukemia	8/11	73	6/7	86
Multiple myeloma [3]	9/13	69	8/11	73
Myelodysplasia [2]	3/6	50	3/6	50
Myelofibrosis [4]	1/7	14	0/4	0
Aplastic-hypoplastic anemia [4]	0/5	0	0/5	2
Total	58/85	68	49/68	72

1 There were 17 cases with case histories only of which 9 were believed to be sufficiently well documented to justify confirmation of the clinical diagnosis (2 AML, 2 CML, 3 CLL, 1 MM and 1 myelofibrosis).
2. Two of the acute leukemia cases were reclassified by members of the panel as cases of myelodysplasia. If they had remained as cases of acute leuekmia the confirmation rate for AL would have been over 96%.
3. Failure to confirm 2 of the myeloma cases was based on the poor technical quality of the slides.
4. No tissue biopsy sections were available for review for any cases of myelofibrosis or aplastic (hypoplastic) anemia.

Table 6.2
Consensus Results of Review of Lymphoma Cases by Expert Panel, Kiev, January 1999
(Task #22)

Diagnoses	Total Cases		Cases with Slides [1]	
	#Confirmed /Total #	% Confirmed	# Confirmed /Total #	% Confirmed
Non-Hodgkin's Lymphoma	11/16	69	11/14	79
Hodgkin's Disease	7/14	50	7/9	78
Total	18/30	60	18/23	78

[1]Failure to confirm some cases was due mostly to poor condition of slide preparations (i.e., faded stain, coverslip artifacts, tissue too thick or fragmented).

Several important problems emerged from the review: 1) overall recovery of slides for leukemia, lymphoma and related disorders from the various oblast hospitals for males in the general population was less than 50% (Table A6.2, Appendix 2) with many fewer (about 25%) being available during the early years of 1987-90; 2) the diagnoses of myelofibrosis, hypoplastic and aplastic anemias rarely were confirmed due to the unavailability of bone marrow biopsies; and 3) recovery of slides from two of the oblasts (Donetsk and Sumskaya) was especially poor, presumably due largely to the local disasters (floods and fires) which had occurred in these oblasts during the early years following the Chornobyl accident.

Subsequent to the review, studies were conducted in one new oblast (Cherkassy). The results for slide recovery for leukemia from adults in the general population were similar to those of the other oblasts (about 50%) and for lymphoma were somewhat better (about 80%). In general, the clinical records and slides were of fair to good quality but slide recovery for the early years again was low.

Studies conducted by Drs. Dyagil and Klimenko after the slide review strongly suggest that slide and record recoveries from several of the oblasts either included in the slide review study or proposed to replace Donetsk and Sumskaya are substantially higher for retrospective cases of leukemia in liquidators than they are for males of comparable age in the general public. Slide recoveries for the

liquidators with leukemia in the oblasts of Dnipropetrovsk, Cherkasy, Chernihiv and Kharkiv averaged 52% (including a low recovery in Kharkiv of only 25% and 100% in both Dnipropetrovsk and Cherkasy) (Table A6.4, Appendix 2). The average medical record recovery rate for liquidators with leukemia in the four oblasts was 81% (Table A6.4, Appendix 2) with uniformly high recoveries in each of the oblasts.

Recent investigations in four oblasts demonstrate that for liquidators with leukemia there is a moderately higher but variable recovery of bone marrow slides and quite uniformly considerably higher recovery of medical records in comparison with males with leukemia in the general population of these oblasts. Also, since the medical records invariably contain information about the diagnostic laboratory studies and the histologic slide review occurrence rates for leukemia and lymphoma were very high, there is considerable confidence in the diagnosis of both of these disorders if only the medical record is available for review. The high rate of medical record recovery combined with over 50% recovery of bone marrow slides for liquidators with leukemia in four oblasts provides the potential for overall case confirmation rates of 80% or more for retrospective liquidator cases of leukemia. The potential for confirmation of retrospective liquidator cases of lymphoma (including multiple myeloma) and myelodysplasia probably is 10 to 20% less than it is for leukemia. Cases of other leukemia-related disorders may be extremely difficult to confirm but careful search of pathology department autopsy and other histologic materials could improve the situation.

Investigating Issues Relating to Leukemia-Related Disorders

Concern has been expressed from the outset that some of the leukemia-related disorders (myelodysplasia, aplastic anemia, hypoplastic anemia, myelofibrosis, polycythemia vera, multiple myeloma, thrombocythemia, etc.) might be in excess in exposed liquidators that their diagnoses might be confused with cases of leukemia, or that they may not have been classified as such. For these reasons the hematology records of the hematology department of clinical hospital #4 in

Dnipropetrovsk were searched for cases of the leukemia-related disorders in the general population for the years 1988, 1993 and 1998.

The results indicate that myelodysplasia was recognized as early as 1987 and that these cases were included in the hospital lists of diagnoses. This study also showed that there were two to three times as many cases of multiple myeloma, aplastic-hypoplastic anemia and myelofibrosis in 1987 as in 1997. There is no clear explanation for about twice the number of cases of multiple myeloma in 1987 as compared to 1997.

In summary, it is reassuring that the hospital records for the earliest year of the proposed study contain the leukemia-related disorders of potential interest to the study.

All of the above diagnoses were checked with the State Registry and ***none*** was listed. Only one patient in the group listed above was a liquidator who was diagnosed with polycythemia vera. Again it should be noted that he was not listed in the State Registry.

The results of the investigation indicate that myelodysplasia should become part of any Phase II study since it may be radiation-related and often closely resembles acute leukemia. The reliable identification of cases of multiple myeloma during the January 1999 slide review, despite its controversial status as a radiation-related cancer, suggests that it should be part of any Phase II study as many of the liquidators are now entering the period of life when they are at greatly increased risk for the disorder. Most cases of aplastic anemia, hypoplastic anemia and myelofibrosis were poorly confirmed at the hematology review but many are recorded at the oblast hospitals and in the Chornobyl Registry. It is likely that some of these cases may actually be cases of myelodysplasia or leukemia and for this reason these diagnoses should be included in any proposed study of leukemia. It would appear on the basis of hospital searches and slide review quite feasible to identify cases of chronic lymphocytic leukemia, Hodgkin's Disease and non Hodgkin's lymphoma in liquidators. Their very low or non-existent relationship to even high-dose radiation exposures,

however, makes them poor candidates for inclusion in a study which is designed to search for low-dose evidence of radiation-induced hematologic disease in the liquidator population. The possibility of obtaining a statistically significant result is extremely low.

7. Selection of Controls

[Tasks 5 & 6]

Controls or sub-cohort members would be selected from the Chornobyl State Registry. Thus, it was important to determine whether or not there would be a significant loss to follow-up using this method to identify controls. This was investigated during Phase I using a sample of liquidators from Dnipropetrovsk as follows:

Men whose addresses at registration were in the Dniepropetrovsk oblast, who were not known to be dead, and who were lacking information for 1997, numbered 4,399 out of a total of 17,809. Of these 4,399, 1,626 (9.1% of the total) had no new information for three or more consecutive years.

Fifty of the latter were chosen at random and from the Registry the following information was extracted: identifiers, certification date and authority, and last known residence. The search for the "lost to follow-up" was performed with the help of responsible persons in the polyclinics of last address. The head of the oblast dispensary department for medical support of Chornobyl victims obtained the assistance of physicians at the raion level as wellas the Ministry of Internal Affairs in the search for the 50 subjects. The present status of the searches is:

- 19 were located and examined
- 9 were railway transport workers whose records were maintained in a subregistry for workers in this industry; they could be located and their health ascertained
- 2 died during 1998
- 2 could not confirm their liquidator status
- 1 is in prison
- 1 emigrated to Israel

- 2 moved to other oblasts
- 3 reside in the rural area of a town that had not been reporting examinations until 1998; one could not confirm liquidator status; contact was made with the other two
- 7 refused to come for examinations
- 2 changed their medical institutions
- 2 moved to other raions

Overall it would appear that the great majority of the "lost to follow-up" could be found, at least 35 out of the 50 minus six ineligibles (due to death or out migration from the oblast). Personal contacts by responsible physicians, mail contacts and passport bureau requests were used to help trace the subjects.

8. Obtaining Data by Interview From Study Subjects

[Task 30]

8.1 Introduction

Information relating to dosimetry and epidemiologic data such as potential confounders would have to be obtained by an interview in a Phase II study. The proposed interview was developed during the Phase I study in collaboration with the International Agency for Research on Cancer (IARC) and investigators from Russia and Belarus, and a workshop was held in Kiev during Phase I to train interviewers (see Dosimetry section). A copy of the interview format is included in Appendix 3.

Also, Phase I investigated means of recruiting study subjects for interviewing and estimated the response rate as follows in 8.2.

8.2 Pilot Assessment of Interviewing Procedures

A sample of 47 persons was selected from the State Registry among the male liquidators who were residents of Dnipropetrovsk oblast and for whom there was no record of death in the Registry. The liquidators were invited for interviews in two successive stages. The first was to extend the invitation

for interview through the responsible physician and, in addition, a letter was sent. The response rate was about 47% (22 persons from out of 47). The second stage was to invite by mail, individually, those who had not appeared for the interview with the proposal to compensate for transport expenses and working time lost. By this means, a further nine subjects attended the interview. Thus, the total response rate was 31 persons out of 47, i.e., about 66%.

The scheme of the engagement for the interview is presented in Table A8.1 (Appendix 2). The interview was conducted by the interviewer trained at the special seminar in Kiev. It was conducted in the oblast dispensary department dealing with the medical support of the victims. Blood was collected following the interview with the written liquidator's consent. Of note, there was no case of refusal to be bled among the persons proposed. The instruction as to the engagement for the interview, interviewing and bleeding is presented in Table A8.2 (Appendix 2). The blood was transferred to Kiev by train in heparinized vacutainers at low temperature (+4-5 C). Being delivered by this way it was fit to be treated in 20 hours. At the hematological department of the Center for Radiation Medicine in Kiev the blood was treated according to the Research Protocol. The mononuclear cells separated were frozen in a freeze at -70 C. Also possible is in-situ preliminary blood treatment in the oblast in case of the transportation time exceeding 20-22 hours.

Data from the inteviews were compared with those on the Registry. A discrepancy between date of birth in the Registry and the questionnaire was found once. The address in the Registry was found incorrect in about 30 % of the cases. All changes of address (except one case) were within the same settlement.

9. Obtaining Biological Samples from Study Subjects

[Tasks 18, 27, 30]

9.1 Introduction

Various biological samples might be collected in Phase II for both cases and controls. These could include tissue samples from cases, pre-treatment blood and marrow samples from cases and blood

from controls, as follows in 9.2.

9.2 Tissue Samples for Cases

Peripheral blood, bone marrow and/or tissues have been obtained during the past 18 months from 25 liquidators (and 2 evacuees) referred to Kiev with hematologic disease (6 with acute leukemia, 5 with CLL, 2 with NHL, 7 with myelodysplasia and 7 with thrombocytopenia and leukopenia) (Table A9.1, Appendix 2). The malignant peripheral blood cells and/or bone marrow from each case was cryopreserved. Tissue storage during Phase I has been principally for the purpose of possible future molecular biological studies.

9.3 Pre-treatment Blood and Marrow for Cases

To date about 10 ml of heparinized pretreatment peripheral blood on several cases of leukemia have been sent from Dnipropetrovsk to Kiev via overnight train for the purpose of possible future cryopreservation of malignant cells for immunophenotyping and other molecular biological studies. The leukocytes were immunophenotyped and an aliquot of separated leukocytes was cryopreserved at -70° C with plans to move them to a -193C freezer in the near future and eventually into liquid nitrogen. No serious problems were encountered in the separation of cells or their cryopreservation. Immunophenotyping by means of flow cytometry on many other patients with leukemia has been completed by members of the immunology staff at the Center. Tentative plans for Phase II also would include preservation of MN red cells for GPA, possible separation of T-cells for FISH, and storage of plasma. Reagents now are in place for red cell MN typing and cryopreservation. To date there also has been no direct tissue immunophenotyping of lymphoma tissue at the Center for lack of trained personnel.

To date 10 liquidators with various hematological disorders have been studied by G-banding cytogenetics. The patients included 3 with myelodysplasia, 2 with chronic myelogenous leukemia, 2 with lymphoproliferative disease, 2 with leukopenia and 1 with leukocytosis. The Ph^+ chromosome was identified in both cases of chronic myelogenous leukemia. Deletion of a

chromosome and duplication of another were observed in the patient with leukocytosis. Few cytogenetic aberrations were identified in the other patient. Although the results of these studies were quite good it is clear that additional training of personnel is needed for karyotyping the malignant cells from persons with malignant hematologic disorders.

9.4 Blood Samples from Controls

To date 10 ml of heparanized venous blood were obtained by a clinic nurse from all 20 of the initially responding liquidators interviewed following completion of their interviews (Section 8). All 20 signed consent forms and were compensated for their expenses.

The blood samples were sent that evening by train to Kiev at 5° C. They were received in Kiev at 8 AM. The mononuclear cells were extracted and stored at -70°C.

Tentative plans in Phase II for the controls or the sub-cohort would be to separate the mononuclear cells for FISH biometric dose estimates and possible molecular biological studies. To date none of the cryopreserved mononuclear cells has been thawed for determination of viability. During Phase II plasma also would be cryopreserved for possible future studies. Since the time lapse between blood procurement and eventual processing in Kiev was only 18-20 hours, it was not necessary to separate out mononuclear cells at the collection site before shipment to Kiev. However, mononuclear cell separation at the withdrawal site may be necessary for blood aliquots from other oblasts with longer transit times. This investigation strongly suggests that cleanup workers who are interviewed will readily cooperate with the signing of the consent form and will donate of a small aliquot of venous blood in return for defrayment of their expenses.

10. Dosimetry

[Tasks 8, 9, 10, 11, 12, 13, 14, 15, 16, and 19]

10.1 Introduction

The main purpose of the dosimetric work was to investigate whether the doses for all clean-up workers involved in the study could be estimated reliably and with acceptable uncertainty. The dosimetry tasks can be grouped into three categories:

- To investigate all available information regarding dosimetry of clean-up workers, both in terms of tasks performed and of doses received during clean-up.
- To establish laboratory facilities and technical capabilities needed for implementation of potentially feasible methods.
- To test different methods of retrospective dosimetry.

The main results are presented for each of the three categories of tasks mentioned above. More detailed information, including experimental protocols, is provided in appendices.

It is important to note that some of this work was done in the framework of the International Dosimetry Group, which was set up in cooperation with the International Agency for Research on Cancer (IARC) in order to harmonize the work carried out in Ukraine, Russia, and Belarus in order to obtain reasonably reliable dose estimates for the Chornobyl clean-up workers.

10.2 Investigation of Dosimetric Information [Tasks 8, 9, 10, and 11]

There are two types of dosimetry sources that are available or can be obtained: (1) the archived information: databases, records, and documents that were prepared when the main clean-up activities were conducted (from 1986 to 1990); this information is dispersed in many locations in Ukraine and in Russia; and (2) the doses that can be reconstructed retrospectively, either by means of instrumental methods (EPR, FISH) or by expert estimation based on personal interviews combined

with a general knowledge of the dose patterns or of the radiation fields (analytical dose reconstruction (ADR), simplified ADR method (DEA), or fuzzy-set method (SEAD)). A description of these dosimetric methods is presented in Section 10.2.3 while supplementary material is provided in Appendices 7 and 8 (EPR), Appendix 10 (FISH), Appendix 11 (ADR and DEA), and Appendix 12 (SEAD).

Four types of activity were carried out:

- Investigation of the dosimetric information available in the Chornobyl State Registry.
- Investigation of other dosimetric sources.
- Investigation of the methods that were used or could be used to reconstruct doses.
- Preparation of a questionnaire for the personal interviews.

10.2.1 Investigation of the dosimetric information available in the Chornobyl State Registry: According to Table A2.3 in Appendix 2, the Chornobyl State Registry contains personal data for 173,125 clean-up workers with known years of service between 1986 and 1990, including 140,948 for 1986-1987. About 50% of those people have "official" recorded doses (ODR), which are derived either from personal monitoring (TLDs, aluminophosphate glasses, and ionisation dosimeters) or from group monitoring (assignment of individual doses based on personal monitoring of a worker who carried out similar tasks at the same time). The distribution of the ODR is shown in Figure A10.1 (Appendix 4). The number of doses given as zeros is 460. Excluding the zero doses and the 120 doses exceeding 2 Gy, the arithmetic mean dose is 119 mGy while the geometric mean dose is 85 mGy; the arithmetic standard deviation is 87 mGy and the geometric standard deviation is 2.7. The number of clean-up workers with dose records from selected Oblasts of residence is given in Table 8.1 (Appendix 2). It is worth noting that there is a very small number of clean-up workers with dose records originating from Kiev Oblast.

Important information that is not included in the Chornobyl State Registry is: (1) the way in which the doses were obtained; (2) the affiliation of the clean-up worker on the Chornobyl site; and (3) the

type of clean-up work that the clean-up worker was involved in. This missing information would have been useful to confirm the validity of the recorded dose levels, as well as to provide indications on the quality of the available dosimetric information. As was demonstrated by Ilyin et al [1995], different organizations involved in clean-up activities had different characteristics both in terms of dose management practices (and, consequently, dose levels) and methods of dosimetry (and, consequently, uncertainties associated with dose estimates). These issues were addressed in a limited postal survey related to clean-up workers from Dnipropetrovsk, Donetsk, Kharkiv, Poltava, and Zaporizha Oblasts.

The postal survey was approached in two steps.

First, the data on home addresses and doses of clean-up workers (as recorded in the Chornobyl State Registry) were received in a form of computer databases. In some oblasts (Poltava, Kharkiv, Donetsk, Dnipropetrovsk and Zaporizha), these lists were checked against the information available at the oblast level; for that purpose, several visits were paid to the local hospitals where clean-up workers receive medical care, as they possess the most up to date information about the status of clean-up workers. These checks revealed that the degree of correctness of names and addresses in the Chornobyl State Registry varies, ranging from 30% in Poltava oblast to 74% in Kharkiv oblast.

In a second step, a postal survey of clean-up workers was undertaken, using special mini-questionnaire forms (see Appendix 5) developed for obtaining information on tasks and affiliation (also offering the possibility to verify the validity of addresses and recorded doses levels). A total of 13,820 questionnaires were sent to clean-up workers, residing in the five oblasts mentioned above (to 100% of the clean-up workers with known home addresses in Dnipropetrovska and Zaporizha oblasts and to 38 to 42% of those clean-up workers in other oblasts). In return, 4,634 completed questionnaires were received (34% response rate). In this way, information about affiliation, tasks, dosimetric practice and location of work was obtained for 7% of the clean-up workers with individual dose record in the Chornobyl State Registry. Results of this survey are quite instructive.

It shows that 86% of the clean-up workers in the sampled oblasts belong to the category of "partisans" (military reservists) and that the percentage of professional atomic workers with presumably good quality dosimetry is very low (less than 3%). The percentage of partisans among respondents from the sampled oblasts was fairly uniform, as shown in Table A.10.2 (Appendix 2).

The most typical tasks performed by clean-up workers were decontamination (62% of respondents), driving vehicles (22%), removal of reactor debris from the roof (19%), and logistic support (17%). Many clean-up workers performed several tasks, so that the percentages given above do not add up to 100%. The most typical localizations of work were the "industrial site" (that is, within the fenced area surrounding the Chornobyl nuclear power plant) and "the 10-km" zone.

The main lesson derived from this postal survey is that the majority of clean-up workers with recorded doses in the Chornobyl State Registry belong to the category of "partisans" (military reservists). This result revealed the importance of the development of approaches: (1) to verify the validity of the dose records for "partisans" that are available in the Chornobyl State Registry; (2) to estimate doses for the "partisans" without dose records in the Chornobyl State Registry; and (3) to evaluate the uncertainties associated with the doses of "partisans."

A general characteristic of the "partisans" is that they had no experience or interest in radioactive decontamination (and therefore have a poor recollection of the work that they performed) and that their doses were obtained through group monitoring. Group monitoring was effected in one of two ways: (1) an individual dosimeter was provided to only one member of a group of clean-up workers assigned to perform a particular task, and all members of the group were assumed to receive the same dose; or (2) a dosimetrist measured the dose rate at the location where the task was to be performed and determined the amount of time that would correspond to the dose allowed for the task that was considered. The military reservists would then carry out their work during the allotted time and would be assigned the allowed dose. The uncertainties associated with group monitoring have been assessed to be up to a factor of 3 [Pitkevich et al. 1995]. In addition, prior to the beginning of the study, concern had been expressed that many doses had been administratively assigned and did

not represent the reality. This concern was based on the observation that many ODR doses are just below 250 mGy, which was the maximum admissible in 1986, and that few are greater than 250 mGy (cf. Figure A.10.1, Appendix 4). However, an investigation of the recorded dose rates seems to indicate that, by and large, the ODR doses have not been falsified [Chumak and Krjuchkov 1998]. This is not to say that all of the ODR doses have to be accepted as true doses. Many exceptions exist and it will be essential to verify in Phase II that the existing individual ODR doses of the subjects selected in the cohort are realistic. In particular, the doses greater than 500 mGy that are recorded in the Chornobyl State Registry should be checked carefully. In a preliminary investigation of the high-dose records of the Chornobyl State Registry, it was found that there were obviously mistyped values and errors in the placement of the decimal point.

In the Oblasts that were sampled, the percentage of professional workers (civilians from the Chornobyl NPP or other nuclear fuel cycle facilities) was very small. However, it is believed that the situation is reversed for the clean-up workers with dose records from Kiev City or Kiev Oblast who were, for the most part, civilian workers (from the Chornobyl NPP or other organizations). It is important to note that there is very little information in the Chornobyl State Registry about the doses received by the clean-up workers from Kiev City or Kiev Oblast because: (1) only a small fraction of the Chornobyl NPP workers is included in the Chornobyl State Registry; and (2) the professionals from other civilian organizations were usually not given a personal dosimeter.

In summary: (1) the Chornobyl State Registry is not complete as only about 50% of the records are associated with a dose value. Results of a limited postal survey seem to indicate that the clean-up workers with ODR doses were mainly military reservists. Most of the clean-up workers originating from Kiev City and Kiev Oblast, the majority of which were professional workers (civilians from the Chornobyl Nuclear Power Plant or other civilian organizations), do not have dose records in the Chornobyl State Registry; (2) the doses included do not seem, on average, to have been falsified, but there is no indication on the manner according to which they are derived; (3) the individual dose estimates need to be checked using supplementary information.

10.2.2 Investigation of other dosimetric sources

In order to verify the validity of the ODR doses and to obtain dosimetric information on workers who are not included in the Ukrainian Chornobyl State Registry, it was necessary to investigate what information is available from sources other than the Chornobyl State Registry. The problem is that after the accident all dosimetric data related to the facilities of All-Union bodies (Ministries, State Committees, etc.) were transferred to Moscow. Then, after the decay of the Soviet Union, a vast amount of information happened to stay in Russia. However, limited databases related to dosimetric monitoring at local facilities remained in Ukraine. In the following, databases for civilian and for military clean-up workers are considered separately:

- The inventory of existing databases with dose records for civilian clean-up workers was conducted by Dr.Victor Krjuchkov (Institute of Biophysics, Moscow) under contract with the National Cancer Institute and in the framework of the activities of the International Dosimetry Group. The effort was restricted to the search for computerized databases with dose records derived from personal monitoring (so called "instrumental dose records"), which are considered to be the most reliable. Six relevant dosimetric databases were found to be available and were obtained. These data were transferred to SCRM for use in the framework of the Leukemia project. Table A10.3 (Appendix 2) contains a summary of the contents of the databases that were obtained.

Upon transfer to Kiev, a vast amount of work was invested into the verification of the database records and into their linkage with the Chornobyl State Registry. Results are presented in Table A10.4 (Appendix 2).

All databases had extremely variable quality from one clean-up worker to another. The most typical drawbacks of the original data were blank fields of dose and incomplete sets of identifiers. Only a small fraction of clean-up workers had unique identifiers (like passport number); in many cases, only surnames were available, and initials for the patronymic and first names.

Therefore, work for refinement of data was needed, having a final goal of standardization of information and linkage with the Chornobyl State Registry database. This work included several of the following steps. At first, the identifiers (i.e. fields which could be used for identification of the clean-up workers with significant degree of reliability) were selected. They were full name and year of birth. After that, selected identifiers were transformed to unified format. Only unique records of databases (i.e. records that differed in at list one of identifiers) were used for the linkage.

As a result, 17,754 persons with dose records were found to possess all identifiers (full name, year of birth). These dose records were good for confident linkage. In all cases, the dose records were available for 1986 and 1987. Additionally, 85,102 records possessing initials instead of full names were selected for conditional linkage.

Eventually, this effort contributed 8,396 dose records related to the results of individual dosimetric monitoring for 1986-1987 clean-up workers who currently reside in Ukraine. However, only 1,893 records (out of 17,754) were linked with certainty with the Chornobyl State Registry, adding 1,613 new data entries, previously missing in the Registry. In addition, 16,097 records (out of 85,102 possessing initials instead of full names) were linked conditionally and require further verification. Information on doses as recorded in the Chornobyl State Registry and in two databases (Chornobyl State Registry vs. the CNII and PERSON databases) was compared for 280 persons. Table A10.5 (Appendix 2) shows that complete agreement was found for 49% of the clean-up workers in this sample, but that there were discrepancies by a factor greater than 10 for 14% of the sample.

- With regard to the military clean-up workers, an important source of dosimetric information is held by the Defense Ministry of Ukraine. The archives of the Defense Ministry of Ukraine (Civil Defense Staff) include dosimetric information on about 35,000 military professionals and reservists (mainly from Kiev Military District). These archives, which exist only on paper, include daily exposures and indications on the manner in which the doses were estimated. It appears essential to obtain this database in order to verify and complement the Ukrainian Chornobyl State

Registry. Partial information (data on three military subdivisions) has been provided to the SCRM. It is likely that the acquisition of the complete database can only be achieved on a commercial basis.

10.2.3 Investigation of the methods that could be used to reconstruct doses

Five methods of retrospective dose reconstruction have been tested or applied in Phase I of the study. Those methods are briefly described here, while a comparison of the results obtained with those methods is provided in section 10.4.

- the electron paramagnetic resonance (EPR) method: this seems to be a reliable method to obtain the dose received by the tooth examined until extraction. The lower limit of detection is in the range from 50 to 100 mGy. Approximately 1,600 teeth from 1052 workers have been obtained and 286 doses have been reconstructed. Unfortunately, the system of tooth acquisition was interrupted due to lack of funding and it may be difficult to obtain a substantial number of additional teeth unless the monetary pump is reactivated. Under the present circumstances, it is not reasonable to expect that teeth can be obtained for every subject in the cohort, so that the EPR technique can mainly be used for dose verification purposes; however, in the long run, the possibility of obtaining teeth from almost all the clean-up workers included in the study, either from dental clinics when they are alive or from post-mortem analysis, cannot be ruled out;

- the fluorescence in-situ hybridization (FISH) method: it is a time-extensive method that was tested in the Cytogenetics Laboratory during Phase I of the study. For that purpose, approximately 50 people covering a large spectrum of doses were bled and FISH analysis performed on those blood samples. According to the literature Littlefield et al. 1998], the lower limit of detection of that method is about 150 to 200 mGy. Therefore, the use of the FISH method will be limited because many of the subjects are expected to have received doses near or substantially below the lower limit of detection and also because of the long time it takes to carry out an analysis;

- the analytical dose reconstruction (ADR) method makes use of the extensive knowledge that some clean-up workers (essentially the Chornobyl NPP workers) have on the clean-up work that they accomplished, combined with a knowledge that some experts have of the radiation fields both inside and outside the plant; this method was used to estimate doses for 2,450 Chornobyl NPP workers and may be used for only a few additional workers for whom comprehensive information is available.

- a simplified ADR method, called "dose expert assessment" (DEA), that could be applied to the remainder of the clean-up workers, is being tested. The DEA method makes use of the questionnaire that was developed jointly with the International Agency of Research on Cancer (IARC);

- the soft expert assessment of dose (SEAD) method, also known as the fuzzy-set method: the principal interest of this method is that it could be applied to any clean-up worker. The method depends upon classifying the entire set of clean-up workers into a discrete number of groups with similar doses, deciding a mean dose for each group, placing the individual considered into one of the groups, and using the answers to a personal interview whether the dose to that individual is higher or lower than the mean dose, and by how much. It is for that reason that Victor Kryuchkov of the Institute of Biophysics in Moscow was funded by NCI through the Columbia University to develop the SEAD method within the framework of the activities of the International Dosimetry Group. It is important to note that this method can lead to satisfactory results only if the mean doses to the selected groups are known with a sufficient degree of reliability. For that reason, Viktor Kryuchkov collected all available information on the doses for civilian clean-up workers that were obtained by means of personal dosimeters.

10.2.4 Preparation of a questionnaire for the personal interviews

At the beginning of Phase I, two types of questionnaire were available: (1) fairly simple questionnaires such as those developed by the International Consortium on the Health Effects of Radiation (called "Consortium" hereafter) for a study of Russian clean-up workers and by the National Cancer Institute (NCI) for a study of clean-up workers in the Baltic countries; and (2) a highly specialized questionnaire developed for use in the ADR method.

Both the Consortium and the NCI questionnaires are designed to provide only general information about time, place and type of work. This is insufficient to determine individual doses with acceptable uncertainty, and only an assessment of a wide dose interval can be made. It should be remarked that attempts to use the Consortium questionnaire to estimate doses have not been successful. The expert assessments tended to overestimate the actual doses in case of low exposure level and to underestimate them in case of high exposure level. These results can be explained as follows: from a general description of clean-up work, it is impossible to find out if high doses were received in high radiation areas, thus resulting in underestimation of high doses; on the other hand, it is difficult psychologically for the expert to assign a small dose to a person who participated in clean-up in 1986, and this results in overestimation of small doses. For these reasons, it is unlikely that expert dose reconstruction with the help of fairly simple questionnaires could be reliable.

The highly specialized questionnaire developed for use in the ADR method consists of a very detailed route list, certified by the competent authorities, in which the whereabouts of the clean-up worker are described. In a subsequent interview, ambiguities as to the location and type of work are corrected, if necessary. Experts from the Scientific Center of Radiation Medicine (Academy of Medical Sciences of Ukraine), the State Enterprise "RADEK" (former Department of Dosimetry Control of Scientific-Production Association "Pripyat"), and the Chernobyl Nuclear Power Plant have used this procedure to assess doses for witnesses of the accident and workers at the Chernobyl Nuclear Power Plant. Unfortunately, this questionnaire can only be used for the limited number of workers who have a clear recollection of their whereabouts during the clean-up operations.

Within the framework of the activities of the International Dosimetry Group, in collaboration with the International Agency for the Research on Cancer (IARC) and investigators from the Former Soviet Union, a questionnaire has been developed for application of the SEAD and DEA methods. This questionnaire, attached as Appendix 3, is more detailed than those of the Consortium and of NCI, but is less comprehensive than the questionnaire used with the ADR method. In principle, this questionnaire could be applied to all clean-up workers. However, the questionnaire used in the ADR method is expected to give better results for the small fraction of clean-up workers with detailed route lists.

A workshop was organized in Kiev, within the framework of the activities of the International Dosimetry Group, in order to train interviewers on how to use the questionnaire developed by the International Dosimetry Group. During that workshop, the questionnaire was tested on about 10 clean-up workers.

10.3 Establishing Facilities [Tasks 13, 14, and 15]

The establishment of facilities for the implementation of dosimetry techniques in view of a possible Phase II included the installation of new equipment, the selection of dosimetric procedures, and the training of personnel. This work concerned the EPR dosimetry and the FISH technique.

10.3.1 Establishing the EPR Dosimetry Laboratory

At the beginning of Phase I, an EPR dosimetry laboratory was already in place, but the equipment was becoming obsolete. Establishing the EPR dosimetry laboratory merely involved the improvement of the existing EPR spectrometer and of a system of tooth collection and management.

Improvement of the existing EPR spectrometer. The EPR spectrometer (BRUKER ECS-106) used at SCRM for methodological research and practical dose reconstruction was significantly upgraded; this upgrade resulted in a notable improvement of its capabilities. This upgrade included installation of the following components:

- Programmable goniometer, the purpose of which is to improve reproducibility of results and to reduce the effect of anisotropy of tooth enamel.
- High sensitivity microwave cavity (resonator).
- High precision gaussmeter (magnetic field meter), which enables adequate determination of the actual magnetic field value at the time of measurement.
- Replacement of the obsolete instrumental computer motherboard with a more recent one, enhancing data storage, spectra manipulation and networking capabilities of the spectrometer.
- Heat exchanger, in order to improve the stability of the measurement conditions.

In addition, the sudden failure of the microwave bridge of the spectrometer during Phase I caused an urgent need to replace the failing HF generator. As a result, the obsolete HF generator (klystron) was replaced with a modern Gunn diode based unit. The advantages of this new hardware are that the EPR signal has a better stability and that the background noise is reduced.

As a result of these modifications, the SCRM spectrometer (initially a multipurpose research instrument) was optimally configured for the needs of EPR dosimetry. Generally speaking, the upgrade allowed both to lower the sensitivity threshold of the technique from 100 to 50 mGy and to improve the throughput of the instrument by a factor of 2. A detailed description of the technical innovations made during Phase-I of the Project can be found in Appendix 7.

In order to take advantage of the new hardware in its use for dose reconstruction, the SCRM EPR dosimetry protocol was modified in accordance with new possibilities of the instrument and modern

views on EPR dosimetry with tooth enamel. As a result, an updated protocol was developed and tested. A description of the modified protocol is given in Appendix 8.

Also, significant improvements were achieved with the modernization of the sample preparation facilities. First of all, a chemical laboratory was equipped with all necessary articles (glassware, protective clothes, labeling materials etc). Also some essential sample preparation equipment was delivered to Kiev. This equipment includes sample grinding hydraulic press, sieves, and a diamond saw necessary for mechanical treatment of the tooth samples. Another important piece of equipment is an ultrasonic bath destined for parallel chemical treatment of many samples of tooth enamel. Soxhlet apparatus are supposed to be used for chemical treatment of dentine (crown and root) for possible use in EPR dosimetry. Some important reagents were delivered as well. The most important reagent that was obtained is heavy liquid powder (sodium polytungstate) used for the purification of tooth enamel.

Altogether, this upgrade of laboratory facilities allowed improvement of capabilities of the Ukrainian laboratory both in terms of throughput and of quality of sample preparation.

Organization of a system of tooth collection and management. The network of tooth collection includes four remote oblast centres: Poltava, Kharkiv, Dnepropetrovsk, and Zaporozha as well as Kyiv City and oblast. The teeth are preserved and delivered in paper bags; their identification is provided in a form previously provided to the clinical centers.

The form, called "Passport for the extracted tooth", and provided as Appendix 5, has significantly changed with time. In order to facilitate the clean-up worker's search from the large number of persons registered in the oblast, it is proposed to request the date of birth. Moreover, it is proposed to formulate in more detail the questions related to the term of service in the 30-km zone. In the previous version of the passport, there was only one question about the year of participation in the clean-up work, whereas now there are questions about the total term, the beginning and the end of the working period. Such detailed information is irrelevant for the retrospective dosimetry using the EPR technique, but may be very useful for the analytical dose estimation.

A significant innovation is the classification of the samples collected in terms of their quality for EPR dosimetry. In order to assess the amount of material valid for dosimetry, a visual examination leading to an estimate of the tooth enamel condition was introduced. The principles of the estimation of the enamel condition are presented in Table A10.6 (Appendix 2). Because of the phenomenon of additional irradiation of the front teeth enamel with hard ultraviolet, which creates the same paramagnetic centers as gamma and x-ray irradiation, only molars and premolars with a sufficient amount of enamel are entirely suitable for dose reconstruction purposes. If a sufficient amount of enamel from molars and premolars is not available, the inner tongue surfaces of incisors can be used.

The estimation of the quality of the collected materials revealed that only 70% of the teeth delivered for the dosimetry measurements are suitable for retrospective dose estimation. It should be noted that the enamel quality of the teeth collected in Kyiv city and oblast is much higher: in the institutions where instructions were repeatedly carried out as to the requirements concerning enamel, nearly 100% of the samples are suitable for investigations; in the institutions where all the teeth extracted are collected, only 18% of the samples may be used for the dosimetry.

Among the teeth samples provided from the oblast centers, the best enamel (60% suitability) is from Poltava oblast, followed by Dnipropetrovsk oblast (54% suitability), Kharkiv oblast (41% suitability), and only 30% of suitable samples from Zaporizha oblast.

It was concluded from these results that an enhancement of the requirements as to the enamel quality is needed. It is envisaged to instruct the specialists during seminars and to disseminate the instructions as to the requirements concerning dosimetric material.

One more problem faced with while working at the project was samples systematization aimed at developing dosimetric material coding system so that each number given to the sample at the stage of sorting would bear complete information on it. Moreover, due to the absence on the forms of medical records numbers which along with complete name of the medical institutions contain information as to the donor of the biomaterial i.e. clean-up worker, we had to introduce our inner

coding. Thus, the numbers of the samples are rather complex however, informative. Perhaps, the numbering system introduced will be improved.

The main drawback, however, remains the insufficient number of collected teeth. Only about 1600 teeth from 1052 workers have been obtained. Unfortunately, the system of tooth acquisition has not been funded for one year and it may be difficult to obtain a substantial number of additional teeth unless the monetary pump is reactivated. Under the present circumstances, it is not reasonable to expect that teeth can be obtained for every subject in the cohort, so that the EPR technique will mainly be used for dose verification purposes; however, in the long run, the possibility of obtaining teeth from almost all the clean-up workers included in the study, either from dental clinics when they are alive or from post-mortem analysis, cannot be ruled out.

10.3.2 Establishing the Biodosimetry (FISH) Laboratory

In contrast to the EPR laboratory, there was no FISH laboratory at the beginning of Phase I. Both equipment and training had to be provided.

Equipment and supplies:

All equipment, reagents and materials needed for the implementation of the Fluorescence In Situ Hybridization (FISH) method at the Cytogenetic laboratory of SCRM have been obtained. They include those needed for: (1) obtaining blood samples; (2) culturing the human peripheral lymphocytes; (3) preparing and storing the fixed cells' pellets; (4) obtaining human metaphase chromosome slides from lymphocytes and bone marrow cell; and (5) implementing the fluorescence in situ hybridization.

The well-known Vysis protocol for the FISH technique has been successfully adapted for the work in the Ukrainian conditions (Appendix 10).

The Cytogenetic laboratory of SCRM is now ready to estimate doses by means of the FISH technique (whole chromosome painting).

Training:

The necessary training related to the implementation of the FISH technique was carried out both in the U.S. and in Ukraine.

- In the U.S.: Dr. M. Pilinskaya and Dr. S. Dibsky visited in November 1996 the Cytogenetic Laboratory of ORISE (headed by Dr. G. Littlefield), where they acquainted themselves with the main steps of the FISH method.

- In Ukraine: Dr. A. McFee from the Cytogenetic Laboratory of ORISE visited the Cytogenetic laboratory of SCRM in February, 1999 and June, 1999. Under the supervision of Dr. McFee: (1) all the solutions needed for FISH probing were prepared and properly adjusted; (2) directly labeled DNA probes were successfully applied to a total 21 slides representing 19 different donors. The fluorescent signal received was quite satisfactory and equal in brightness to that obtained in the U.S. cytogenetic laboratories; (3) about 2100 painted metaphases from 3 clean-up workers were scored. Each chromosomal abnormality that was found was discussed jointly in order to help insure agreement in the scoring criteria to be used; (4) the P A I N T classification for the types of chromosomal aberrations to be taken into consideration under the cytogenetic investigation of FISH slides was coordinated (according to Tucker et al., 1995) and a form for recording the results of FISH scoring was developed; and (5) many discussions were held regarding procedures for the examination of FISH slides, scoring chromosomal abnormalities, and for calculating absorbed radiation doses.

10.4. Testing Dosimetric Methods: [Tasks 10, 14, 16, 17, 19]

The dosimetric methods that were considered are:

- EPR (Electron Paramagnetic Resonance) dosimetry with teeth.
- ADR (Analytical Dose Reconstruction) developed and used, predominantly, for professionals from the Chernobyl NPP staff.
- SEAD (Soft Expert Assessment Dosimetry) developed by the International Dosimetry Group and intended for evaluation of doses to all categories of liquidators. It is calibrated using the available instrumental dosimetry data and based on the analysis of the dosimetric questionnaire.
- DEA (Direct Expert Assessment) or mADR (modified ADR) – the version of ADR revised in order to make it applicable to all categories of liquidators. This technique makes use of the same dosimetric questionnaire as SEAD.
- FISH (Fluorescent In Situ Hybridization) – biodosimetric method which scores stable translocations in human blood lymphocytes and relates translocation frequency to dose.

The test of dosimetric methods was organized in the form of cross-calibrations according to which different methods were compared to each other and related to a defined reference, or "Gold Standard" (GS) method. Since among all listed above dosimetric techniques, EPR dosimetry is the only instrumental method which provides strictly quantifiable results and uncertainties, it was assumed as GS. Internal consistency of EPR and of its performance were checked using several independent tests.

Basically this work was carried out in course of several exercises. These exercises namely were:

- Test of ADR on 20 professional workers having doses evaluated by EPR.
- Test FISH on 49 liquidators possessing EPR and ADR dose estimates.

- Test SEAD and DEA on 50 subjects having EPR dose. This test also envisaged addressing such issues as evaluation of robustness of SEAD by comparison of results coming out from analysis of the same dosimetric questionnaires by different experts and also by independent evaluation of doses when questionnaires were filled out not by liquidators themselves, but by their proxies (simulation of the post mortem dose reconstruction case).

It is important to note that the purpose of these tests was to find out whether, or under which conditions, the dosimetric methods that were considered provided dose estimates that were consistent with those obtained using the EPR method, which was deemed to be the most reliable. Another important issue, which is the investigation of the validity of the Official Dose Records (ODR) for all categories of clean-up workers, was not part of the Phase-I activities, but should have a high priority in any Phase-II study.

10.4.1 Tests of EPR dosimetry:

EPR dosimetry with teeth has a long record of different tests and cross-calibrations [Chumak et al. 1997; Haskell et al. 1997]. Among those tests, the most clear cut judgement of the performance of the EPR dosimetry is provided by blind intercalibration when test teeth are exposed *in vitro* to precisely determined doses and then measured by EPR dosimetric laboratories which do not know the nominal dose values. Among intercalibrations of this type, the most notable are the 1st and 2nd International Intercomparisons of EPR Dosimetry with Teeth, which were carried out in 1994/95 and 1998/99 under the auspices of the International Atomic Energy Agency (IAEA) [Chumak et al. 1996; Wieser et al. 1996; Wieser et al. in press]. The SCRM EPR laboratory took part in both intercalibrations and proved its ability to reconstruct dose in excess of 100 mGy with average error of about 20%.

The 2nd International Intercomparison involved 20 laboratories from different countries. Both SCRM and its American counterpart – the Center of Applied Dosimetry in Salt Lake City, UT (CAD) - participated in this intercomparison. According to the design of the intercomparison, participants received 5 tooth samples exposed in the secondary standard laboratory (IAEA) with doses in a range

from 0-1 Gy, unknown to participants. The task was to conduct a full range EPR analysis and to determine the unknown dose values.

The results demonstrated by SCRM in the first test series are of unequal quality. As may be seen in Figure A10.2 (Appendix 4), the samples may be divided into two groups: those for which doses were reconstructed with exceptionally good accuracy and precision (error of less than 5%) and others with an error of about 20-35%. The mean deviation for all samples was 20%. The first group includes samples with nominal dose values below 200 mGy, the second – with doses above 200 mGy. The larger uncertainty obtained for high dose samples is a sort of paradox, though the samples of the first group are most frequent among clean-up workers and constitute the highest interest from the point of view of epidemiological needs. A possible interpretation of the deviations found for some samples lays in the fact that, as it was discovered later, the intercomparison measurements were conducted using a failing EPR spectrometer. Spectrometer failure was manifested in enhanced noise level leading to larger uncertainties in the reconstructed doses. A less probable reason of discrepancies is the use of several, not sufficiently tested, innovations in the course of dose reconstruction: (1) use of the programmable goniometer in order to reduce anisotropy effects; and (2) multiple replacement of resonators (after each irradiation) which was endowed with replacement of Mn^{2+}:MgO standard. This may also lead to additional uncertainty.

In order to clarify the causes of the discrepancies mentioned above, it was decided to organize a second blind test series involving only two laboratories – SCRM and CAD. The design of the second test series is quite similar to the first one with one exception - both laboratories received halves of the same teeth, thus removing possible effects of variation in the composition of the teeth and in the conditions of exposure. Irradiation of teeth was conducted in the same IAEA laboratory as in the first case.

The evaluation of the doses received *in vivo* may face additional difficulties due the exposure to additional sources of radiation such as UV light (in particular, solar) and X-ray medical doses. Not

taking proper account of these confounding factors may lead to over-, or underestimation of doses; by its nature, the EPR signal includes components from various sources of radiation. Special attention was paid to the prevention of the effect of these confounding factors. In order to eliminate a possible bias due to uncontrolled UV and X-ray irradiation, special selection of the tooth samples was performed. Only molars and premolars (which do not receive solar UV radiation) were used for the tests; subjects were selected by the criterion of absence of significant X-ray examinations (none or occasionally one X-ray examination was allowed for the subjects included into consideration; information about the number and nature of the X-ray medical examinations was obtained from the tooth ID form presented in Appendix 9.

10.4.2 Test of conventional ADR on 20 workers:

The technique of analytical dose reconstruction (ADR) was tested on 20 randomly selected workers. In the design of this test, the EPR dosimetry was taken to be the reference dosimetric method (GS). Therefore, the 20 liquidators were selected according to the following criteria: (1) the dose of the candidate had been reconstructed by EPR, and (2) the liquidator was a ChNPP staff member and the ADR method was applicable to this person.

The technique of analytical dose reconstruction (ADR) is based on the compilation of the description of liquidators' professional route with the information on dose rate fields in the locations where the liquidator spent time. The description of the technique is given in Appendix 11. Application of the ADR method requires a good knowledge of the circumstances and locations of work by the liquidator. Therefore, due to this intrinsic limitation, from the very beginning of its development, ADR was restricted to professional workers of the Chernobyl NPP. Since 1989, this technique has been extensively used at the Department of Retrospective Dose Reconstruction of the Chernobyl NPP. All together, doses to 2450 employees of ChNPP have been reconstructed in this way. Most

of the employees with ADR reconstructed doses are Ukrainian (86%); approximately 23% are in the Chornobyl State Registry.

The analysis of "route lists" was conducted in the way as it is usually done in the course of dose reconstruction. According to this procedure, retrospective dose evaluation for each liquidator should be performed in two stages:

- Expert assessment of primary data on exposure levels basing on a filled out questionnaire and a liquidator's route list. At this stage, the route list is split by an expert into a set of "episodes" corresponding to completed phases of work. Then, each episode is divided into separate "frames", i.e. time intervals during which dose rates could be considered as constant.

- Retrospective dose reconstruction itself. At this stage, an individual dose is evaluated using data on dose rates on a route.

In principle, the estimation of the dose is based on the theory of fuzzy sets. The main result of the assessment according to this procedure is expressed in terms of most likely dose and of maximum possible dose (see Appendix 9 for details). An experienced expert divides a route into episodes and frames, evaluates their duration and the corresponding dose rates for those time intervals. Then, by multiplying these parameters, the expert calculates a maximum possible dose on the route. In order to obtain the most likely dose, the maximum possible dose is multiplied by a factor ranging from 0.42 to 0.51 according to the time of exposure (see Table A7.2, Appendix 11).

In fact, the dosimetry experts are not familiar with the details of the fuzzy set approach and, contrary to the instructions given to them, simply sum up pre-calculated standard episode values or evaluate doses related to rather unique episodes. This leads to systematic bias (overestimation) in the estimated doses mainly because of two reasons. First, the use of the maximum possible dose rate and

duration of frame for the estimation of the dose per episode (systematic overestimation of the dose in case of doubt) and lack of conversion back to the most likely dose value leads to roughly doubling the dose. Second, the use of officially approved pre-calculated doses per standard episodes (such as transportation or passage by established routes) leads to significant overestimation of total doses; reevaluation of some "standard episode" doses revealed an almost ten-fold overestimation. A more detailed discussion of these effects is given in Appendix 11. If the first factor may be accounted for relatively easily (this correction was done in the DEA assessments below), the second source of overestimation is much more difficult to evaluate.

Another term of uncertainty is caused by random error of dose evaluation associated, primarily, with expert evaluation of a route list. In order to test variations caused by the difference in evaluation by experts, three independent practitioners were asked to analyze route lists and conduct separate dose assessments. Despite the predictions that the discrepancies between the experts' estimates will occur in case of person's service in non-uniform radiation fields, no discrepancies are found in such cases - the estimates coincide.

The comparison of the ADR and EPR dose estimates for the 20 individuals revealed significant discrepancies in some cases as could be seen from the scatter diagram presented in Fig.A10.3. Actually these discrepancies cannot be eliminated just by multiplication of the calculated ADR dose by a factor of about 0.5. Detailed dose formation components and origin of overestimation are considered in Appendix 11 after the detailed description of the ideal ADR protocol.

The main conclusion derived from the testing of ADR is that the technique cannot be used for the needs of the Project without substantial revision and improvement.

10.4.3 Tests of SEAD and DEA on representative groups of liquidators:

These tests were performed in the framework of the International Dosimetry Group. The demand for a universal and robust method of dose estimation for ***all*** subjects, including those who are diseased and possibly died, prompted an extensive work program on the development of the SEAD and DEA methods. The tests addressed questions of applicability of SEAD and DEA to different groups of liquidators. Regarding the peculiarities of exposure (and doses received) in Chernobyl, three main groups were identified as:

highly skilled professional workers;

military reservists, also called "partisans", without particular skills or motivation, and

short-term civilian visitors to the 30-km zone, so called "Sent On Mission" (SOM).

The tests were performed in the following manner:

- the European group tested SEAD and DEA on professional atomic workers. In the absence of EPR measurements, the dosimetric monitoring at the time of clean-up was considered to be the reference method, or "Gold Standard" (GS). In order to achieve this task, 50 professionals who worked in Chernobyl were interviewed in Russia (most of them in Obninsk); and
- the Ukrainian-American group concentrated on testing the methods on military reservists ("partisans") and civilians who were sent on mission to Chernobyl (SOM). EPR dosimetry was used as GS for these categories of clean-up workers. Another issue addressed by the Ukrainian-American group was the evaluation of the feasibility to use information acquired from proxies (Chornobyl co-workers and relatives) of the liquidators. The Ukrainian group consisted of 41 SOM, 9 "partisans" and 35 proxies (27 related to SOM and 8 to "partisans"). Interviews were conducted by trained interviewers who used the dosimetric questionnaire. Fifteen interviews (related to "partisans" and their proxies) were taken in Poltava oblast, while the rest of the interviews were carried out in Kiev.

In order to check robustness of the methods and evaluate effect of subjective factors on the results of dose reconstruction, doses were independently evaluated by two SEAD and two DEA experts.

Results of comparisons are presented in Figures A10.4 to A10.6.

It may be seen (Fig. A10.4), that both SEAD and DEA demonstrated both significant scatter of results (random error) and offset (systematic error). Parameters of the respective ratios distributions are presented in Table A10.7.

It is clearly seen from the table that on average both methods (SEAD and DEA) perform with comparable degree of both random and systematic error relatively to GS (in this case – results of individual dosimetric monitoring) for professional atomic workers. It may be concluded (under assumption of lognormal distribution) that both methods overestimate doses by 1.6-1.7 times (GM) with relative error of 2.8-2.9 (GSD) when all dose estimates are taken into account. It appears, however, that the SEAD and DEA doses are overestimated for GS doses between 0 and 20 mGy and underestimated for GS doses above 100 mGy. Despite the seeming similarity of the two methods, correlation between each other is quite poor too (r=0.67). The slope of the curve DEA(SEAD) is 0.79 (the case of ideal agreement corresponds to the slope 1).

In case of SOM (Fig. A10.5), particularly for low EPR doses, both SEAD and DEA systematically underestimate doses, although DEA provided less biased assessments. After reconsideration of some DEA assessment (for instance, account of low speed movement in case of cleaning roads or account of contaminated clothes), DEA assessment got closer to EPR value. Characterization of both systematic bias and random error is given in Table A10.8.

It is worth mentioning that this analysis involved point assessments provided by given dosimetric methods. Consideration of respective uncertainty intervals gives somewhat more optimistic picture. As may be seen from Fig. A10.5, uncertainty intervals for GS (EPR, in this case) and DEA considerably overlap in most cases.

For military reservists ("partisans") (Fig. A10.6), SEAD either agreed with GS dose values, or significantly overestimated them. Closer consideration of these results revealed that "partisans" whose SEAD assessments are higher than GS doses are residents of Poltava oblast and belonged to the same military unit. This military unit worked at the periphery of the 30-km zone and performed tasks that were not associated with exposures as high as in the 10-km zone. Other cases, where coincidence was better, correspond to "typical" military reservists who performed clean-up within the 10-km zone.

The sources of such discrepancies, most likely, lay in the intrinsic organization of SEAD. The matter is that SEAD bases its prediction on generalization of large data arrays related to given categories of liquidators. The better and more complete is the original information on dose distribution, the more adequate results SEAD produces. When the liquidator, whose dose is evaluated, matches some group for which a good deal of source information exists, this information is applied in straightforward manner and prediction of dose is quite accurate. However, problem occurs, when extrapolation, i.e. application of regularities determined for one group to the members of different (although, likely) group, is needed. Apparently, SEAD fails to do this appropriately.

This point is confirmed by the observations acquired in course of test exercise. So, for professional workers, where extensive and high quality dosimetric data exists, SEAD estimates were in best (yet not really satisfactory) agreement with GS (in this case – dosimetric monitoring data) doses.

A reliable information base for SOM is missing because almost none of them wore individual dosimeters during their short visits to the 30-km zone. The dose distributions used for SOM are based on extrapolations from other liquidator categories was used, leading to significantly biased results. Calibration for "partisans" was performed on very large data arrays which are related to military liquidators who performed their work at the industrial site of ChNPP. Consequently, the doses to "conventional partisans" were predicted quite well, while significant overestimation took place for "partisans" of different types (called thereafter "peripheral partisans").

In general, the encountered problems are related rather not to the method (SEAD) itself, but to limitations of its information basis. One may expect that if sufficient and adequate information basis exists for the given category of liquidators, prediction by SEAD will be more satisfactory. In fact, this hypothesis is confirmed by rather systematic bias in case of Poltava "partisans".

In conclusion of this discussion we should mention that additional training or "calibration" of SEAD is needed in order to improve its ability to predict doses. Since the most numerous groups of liquidators are SOM and "partisans", it might be sufficient to address calibration of these two categories only. Another improvement may be brought by better categorization (grouping) of liquidators. This measure may help to exclude undesirable extrapolation from one groups to other.

Calibration concerning "partisans" may be achieved quite easily by use of the data arrays separated with respect to the type of "partisans" – "conventional" or "peripheral". In this case two sub-categories should be created, to be applicable to the two groups of "partisans".

Calibration of SEAD for SOM is not that trivial. Unfortunately, there is no (extremely limited) reliable data on their individual exposures, which may be used for calibration purposes. Therefore, calibration using EPR dosimetric results may be envisaged. Of course, this approach would require time and labor needed for reconstruction of several thousands of EPR doses, but this may be the best way to calibrate SEAD on SOM.

Another important issue which was studied in course of the discussed testing is evaluation of robustness of SEAD. Two aspects were studied:

Degree of invariance of SEAD results on expert's personality:

Ability to provide consistent results using responses to the questionnaire, given not by liquidator himself, but by his proxies. This test was particularly important because of need to evaluate doses to all, including died subjects. In this case, proxies should be interrogated attempting to evaluate liquidator's work in Chernobyl and, respectively, dose.

The first aspect was achieved by consideration of the questionnaires by two different experts. One of the experts was Dr.Krjuchkov – the author of SEAD and extremely well informed liquidator himself. Another expert had no Chernobyl experience and was trained to use SEAD by means of operation manual developed by the authors of SEAD. Comparison of the results provided by two experts revealed extremely high degree of coincidence. Correlation coefficient was at high as 0.9. The discrepancies between two expert assessments (a total of 5 cases with a dose ratio greater than 2) were discussed by the experts and in some cases experts' errors were identified. In general, SEAD demonstrated remarkable robustness in terms of low effect of expert's subjective judgement.

The second aspect (evaluation of proxies) got high impact value at the very late stage of the Phase I of the project and, therefore only preliminary results are available for the time being. In case, if Phase II of the project will be initiated, one of the high priority tasks will be to study this problem in more depth.

The test of proxy dose assessment was organized in following manner. Each of "partisans" enlisted to the interviewing was invited to bring his proxies. It was stressed, that it would be preferable if two proxies (Chernobyl co-worker and wife or other close relative) may come to interview. Indeed, some liquidators brought both proxies to the interview. In other cases either wife or co-worker served as a proxy. Interrogation itself was performed in the way preventing influence of liquidator's responses on proxy's opinion (interview was carried out in a closed room, one interview at a time; the liquidators were not informed in advance about the nature of the questions that were going to be asked). In the course of the analysis of the filled-in questionnaires, special consideration was paid to the investigation of the possibility that a proxy was given information by a liquidator; no such occurrence was found.

As may be seen from Fig. A10.6, the SEAD assessments derived from interviewing liquidators themselves and from the questionnaires filled out by proxies has shown remarkable overlap of dose assessments. It turned out that SEAD works well even with questionnaires completed by the proxies. Obviously, uncertainty ranges for proxy dose assessments are broader; as a rule wives know less

details about circumstances of liquidator's work in Chernobyl and, therefore, uncertainty ranges in this case are wider.

The responses from 11 proxies were analyzed during Phase-I of the study. A somewhat larger number would be interviewed at the beginning of any Phase-II study, in order to investigate the uncertainties associated with that method.

In conclusion, SEAD has demonstrated robustness both in terms of expert invariance and ability to use surrogate information source for the evaluation of the external doses received by liquidators. However, the systematic biases that were detected for some groups of liquidators indicate that further calibration and improvement of the method are warranted.

10.4.4 Testing the FISH method :

In October 1998, the protocol describing the procedure of FISH testing was agreed and its implementation began. It was assumed in the protocol that :

- 50 FISH analyses must be restricted to the subjects with independent dose assessments provided by the following methods: EPR with teeth, ADR performed for Chemobyl NPP staff on the basis of the analysis of time-and-motion information, and Official Dose Records (ODR) available from the State Chernobyl Registry of Ukraine.
- None of high dose subjects who had suffered from acute radiation syndrome (ARS) and are lacking dosimetric information of the mentioned above kinds will be included into the bleeding process.
- Among those 50 subjects, the group of 10 persons with doses below 100 mGy will be considered as control (background) sample.
- The age of enlistees will not be limited at the stage of the selection process. In this case, results of a calibration study will be applicable to any members of cohort in the future. However, FISH will use the age of subjects as a parameter in the evaluation of dose.

In the course of the selection of candidates for FISH, the following priorities will be considered:

- Attempts will be made in to maximize the sample with triple (i.e. EPR-ODR-FISH or EPR-ADR-FISH) and quadruple (EPR-ODR-ADR-FISH) dose assessments. Because of the very limited number of such subjects, no or only limited discrimination in terms of dose distribution will be applied to this group.
- The remainder of the 50 subjects will be selected in such a way to provide the following dose distribution:

0-100 mGy (control Sample)	100-250 mGy	250-500 mGy	500-1000 mGy	>1000 mGy
10	X	(40-X-Y)/2	(40-X-Y)/2	Y

where X is determined by the actual number of triple and quadruple dose subjects falling into the dose range 100-250 mGy, but no more than 5, and Y is determined by the actual number of high dose subjects (with dose in excess of 1000 mGy), but no more than 10.

- When considering the estimated dose, the following procedure should be used for treatment of subjects with multiple dose assessments: if one of the dose assessments is provided by EPR, this dose value will be used for allocation of individuals to one of the dose groups; if none of the assessments is EPR, an average of two dose estimates should be used."

When the intercalibration protocol was designed and adopted, the selection of candidates for FISH sampling was made according to the above mentioned protocol. First of all, attention was paid to the selection of liquidators with high quality doses reconstructed by EPR or to those persons who had donated their teeth and whose doses might be reconstructed using this technique. When the original list, containing 114 liquidators was composed, enlistment to the study was initiated. Liquidators were contacted by mail (70) or by telephone (44). After persistent attempts to recruit only liquidators with EPR doses, only 37 subjects could be enlisted, distributed mainly in low dose groups. Then,

the recruitment process shifted to liquidators with ADR. Eventually, 53 liquidators were invited to the laboratory of cytogenetics for bleeding and FISH analysis. All samples of venous blood were drawn by qualified medical personnel, each liquidator received monetary compensation ($10) for the possible inconvenience caused by his travel and donation of blood. The majority of study subjects were males (90%) with age ranging from 37 to 73 at time of bleeding.

About 5 mL of venous blood was taken in the cytogenetic laboratory from all donors investigated previously with the help of the EPR method or of some other method of dosimetry. The doses estimated by other methods were unknown to the persons responsible for performing FISH evaluations.

All whole blood samples were processed and scored according to the established procedure (see Appendix 10 for details). For dose reconstruction purposes, only the frequency of reciprocal translocations and insertions was used.

FISH hybridization was conducted for 53 subjects, 3 of them were later withdrawn from the comparison due to dosimetric considerations[2], in one case hybridization failed. Therefore, doses were reconstructed by FISH for 49 liquidators, covering the prescribed dose range. The breakdown of subjects by dose intervals and methods of dosimetry is presented in Table A10.9 (Appendix 2). It may be seen from the table that 32 subjects were analyzed by EPR dosimetry, 32 by ADR and 3 by ODR. None of the ODR subjects overlap were also analyzed by ADR, while there are 15 EPR-ADR pairs.

It is worth mentioning that the EPR method was generally used as the reference (GS) method to which FISH results were compared, while the ADR results were used to a limited extent. The results

[2] In course of closer consideration of dental material, it turned out that these liquidators had donated front teeth, not suitable for EPR dosimetry.

of FISH analysis are presented in the Table A.10.10. Wide inter-individual variability in the frequencies of stable chromosome aberrations inside the all groups was established.

In order to estimate doses using the FISH technique, it is necessary to compare the observed numbers of translocations in individual liquidators with the numbers of translocations induced in human lymphocytes exposed to radiation in vitro. It is well known that the numbers of radiation-induced chromosome aberrations such as translocations depend not only on radiation dose, but also on radiation quality (i.e., whether the radiation exposures were to sparsely ionizing or low-LET radiation such as gamma rays, or to densely ionizing radiation, such as neutrons). To date, in vitro calibration curves have been generated using FISH methods for several radiation qualities including gamma radiation, x-rays, and neutrons, and dose response coefficients are available in the literature. In this study, it was assumed that penetrating low-LET gamma rays emitted by Cs-137 were the primary contributors to marrow dose among liquidators, so that dose response were used to estimate doses. For low-LET radiation, it is also well known that aberration induction depends on the rate at which the radiation was delivered. Low-LET radiation is much more efficient in inducing translocations in human lymphocytes when exposures are delivered at high dose rates than when doses are protracted over long periods of time. The exact exposure scenarios of most liquidators are not known; it is possible to some of them received acute high dose rate exposures while others may have received more chronic exposures at very low dose rates. To take into account both possible exposure scenarios, individual doses were calculated using two in vitro calibration curves, one for translocations induced in human lymphocytes exposed to high dose rate gamma rays (i.e., "acute" curve) and for translocations induced in human lymphocytes exposed to gamma rays exposed to gamma rays delivered at very low dose rates (i.e., "chronic" curve). Both curves were generated by scoring translocations in painted chromosomes 1, 2, and 4, and converting observed frequencies to total genome frequencies. Doses were then calculated using the linear quadratic dose response function: $N = \gamma + \alpha D + \beta D^2$, where N is the total genome frequency and D is the bone-marrow dose.

Results are compared to the doses obtained using the EPR method in Figure A10.7[3]. According to this figure, experimental data show significant scatter. Linear regression analysis revealed very little correlation between FISH and EPR dose estimates for individual liquidators. The best correlation ($R^2 = 0.67$) was observed when the "acute" calibration curve was used to estimate the FISH doses.

It was also attempted to determine whether better correlation would be observed between EPR and FISH dose estimates when comparisons were made with groups of individuals with specific dose ranges (Figure A10.8). In persons exposed to doses less than 250 mGy, doses estimated by FISH were considerably higher than the corresponding EPR dose estimates. For comparisons made in liquidators with higher doses, much better agreement was observed between the two endpoints.

The large disparity between EPR and FISH dose estimates is most likely due to the lack of sensitivity of FISH in discriminating effects after in vivo exposures to low doses of radiation. FISH techniques can readily detect and quantify doses of as low as 100 mGy in human lymphocytes irradiated under highly controlled in vitro conditions. The method is severely compromised when used to detect low levels of radiation exposure that occurred in vivo because of high and variable frequencies of translocations that are observed lymphocytes among persons having no exposure other than background radiation. Although trends toward higher translocations are observed with increasing age and among current smokers, attempts to apply statistical corrections for these confounding variables do little to reduce the observed heterogeneity between individual control subjects. Thus, at present, the high and variable background frequencies of translocations preclude the use of FISH in estimating doses of less than 300-500 mGy in persons exposed to low-LET radiation.

For the sake of completeness of presentation of the results, scatter plots illustrating results of pair comparisons are presented in Figures A10.9 (ADR vs. EPR) and A10.10 (ADR vs. FISH). In

[3] In this and other figures, the line corresponding to the ideal agreement between two dose estimates is plotted in order to provide a visual assessment of the results.

addition, all EPR, ADR, and ODR data are plotted against the FISH dose estimates in Figure A10.11.

10.4.5 Summary:

• For limited samples of liquidators, the results of dosimetric methods, other than ODR, that are considered for estimating doses to liquidators were compared to each other and related to a defined reference, or "Gold Standard" (GS) method.

• The dosimetric methods that were investigated were: EPR (Electron Paramagnetic Resonance), ADR (Analytical Dose Reconstruction), SEAD (Soft Expert Assessment Dosimetry), DEA (Direct Expert Assessment), and FISH (Fluorescent In Situ Hybridization). Since among all listed above dosimetric techniques, EPR dosimetry is the only instrumental method that provides strictly quantifiable results and uncertainties, it was assumed as GS.

• Internal consistency of EPR and of its performance were checked using several independent tests. The SCRM EPR laboratory took part in are the 1st and 2nd International Intercomparisons of EPR Dosimetry with Teeth, which were carried out in 1994/95 and 1998/99 under the auspices of the International Atomic Energy Agency (IAEA) [Chumak et al. 1996; Wieser et al. 1996; Wieser et al. in press] and proved its ability to reconstruct dose in excess of 100 mGy with average error of about 20%. However, the evaluation of the doses received *in vivo* may face additional difficulties due the exposure to additional sources of radiation such as UV light (in particular, solar) and X-ray medical doses.

• The comparison of the ADR and EPR dose estimates for 20 individuals revealed significant discrepancies that are due to systematic overestimation of the doses by the ADR method. The main conclusion derived from the testing of ADR is that the technique cannot be used for the needs of the Project without substantial revision and improvement.

• SEAD and DEA were tested for three main groups of liquidators identified as: (1) highly skilled professional workers; (2) military reservists, also called "partisans", without particular skills or

motivation, and (3) short-term civilian visitors to the 30-km zone, so called "Sent On Mission" (SOM). SEAD demonstrated robustness both in terms of expert invariance and ability to use surrogate information source for the evaluation of the external doses received by liquidators. However, the systematic biases that were detected for some groups of liquidators indicate that further calibration and improvement of the method are warranted.

• The FISH technique was tested on a sample of 49 liquidators and results were compared mainly with those obtained using the EPR method. At dose below 250 mGy, a large disparity between EPR and FISH dose estimates was observed; this disparity is most likely due to the lack of sensitivity of FISH in discriminating effects after in vivo exposures to low doses of radiation. At present, the high and variable background frequencies of translocations preclude the use of FISH in estimating doses of less than 300-500 mGy in persons exposed to low-LET radiation.

• It is important to note that the purpose of these tests was to find out whether, or under which conditions, the dosimetric methods that were considered provided dose estimates that were consistent with those obtained using the EPR method, which was deemed to be the most reliable. Another important issue, which is the investigation of the validity of the Official Dose Records (ODR) for all categories of clean-up workers, was not part of the Phase-I activities, but should have a high priority in any Phase-II study.

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11. Selection of High Dose Group

[Task 7]

11.1 Introduction

During Phase I, the feasibility of assembling a "high dose" (>0.5 gray) group of liquidators from all over Ukraine was investigated for future possible molecular studies. In addition, blood samples were obtained from some members of the group and some biological dosimetry (FISH) was also performed as follows.

11.2 Identification of High Dose Sample

Relevant files were found to be those of the Institute of Clinical Radiology in the Research Center of Radiation Medicine, the Chornobyl Registry, the 25th local hospital, the Ministry of Internal Affairs hospitals and files of the Ministry of Internal Affairs itself, Central, Kiev, Kharkov specialized councils on the estimation of the relationship between deterioration in health and participation in Chornobyl accident cleanup work, the archive of the CNPP, and the archive of the Republican dispensary of radiation protection.

About 1,800 liquidators in Ukraine now have been identified at RCRM and through the Registry with radiation dose estimates in the high dose range with the expectation of going over 2,000. The dose estimates in these individuals will need further verification. A separate file of the identified high dose group was created.

11.3 Blood samples and Biological Dosimetry

To date mononuclear cells have been separated and cryopreserved at -70°C on 27 liquidators in the high dose category. FISH cytogenetics for stable chromosome aberrations as an index of radiation dose were completed on about 10 liquidators in this group over a year ago with scoring at Livermore by Dr. Pilinskaya and by Dr. Littlefield in her laboratory. The correlations were excellent. No red cells were typed for the MN antigens or cryopreserved since the reagents for these procedures were unavailable until only recently.

APPENDIX 1

LIST OF TASKS

Appendix 1

List of Tasks

Task 1 Investigate Registry

1) Develop a conceptual model of the State Registry of Ukraine with a description of the items of information needed for the database.
2) Determine the items of information in the individual files that will be selected for each member of the cohort (and subcohort) in the formation of the cohort (and subcohort) database.
3) Explore the feasibility of the transfer of data from the Chornobyl Registry to the database for the project.

Task 2 Obtain Registry Tabulations

Obtain tabulations characterizing the participants in the liquidation of the effects of the Chornobyl accident; of particular interest are tabulations of age, sex, year of service, any recorded dose, last known residence, identifiers, and frequency of follow-up examinations as well as date of registration as a clean-up worker.

Task 3 Verify Record Linkage

Obtain descriptions of any existing procedures for linking the Registry with other files.

Task 4 Begin to Assemble Cohort

1) Begin to create the cohort file consisting of men who participated in the accident work in 1987-1990, living at the time of registration in six areas: Dnipropetrovsk, Donetsk, Karkov, Sumy and Kiev oblasts, and Kiev City. (The variables to be taken from the Registry for each person will have been decided in Task 1.)
2) The newly created file will be placed on the server of the Center for Information Technology and State Registry of the Ukrainian Ministry of Health and on that of the Scientific Center for Radiation Medicine, Ukrainian Academy of Medical Sciences.
3) A representative subcohort of 1,000 subjects will be formed from the full cohort according to specifications to be developed.

Task 5 Lost to Follow-up

1) "Lost to Follow-up" will be will be defined as men for whom no information has been entered in the State Registry for three or more years.
2) Twenty such men who entered the Registry through the Dnipropetrovsk oblast facilities will be chosen at random from those eligible under the above definition.

Task 6 Search for Lost to Follow-up

1) Request latest address from dispensary or polyclinic where last seen.
2) Direct-mail inquiry to clean-up worker at latest address asking why he has not been in for an examination lately.
3) Consult other resources for men who do not reply or cannot be found.

Appendix 1: List of Tasks (cont.)

Task 7 Identify High-Dose Sample

1) Identify the files that contain dose information.
2) Select men with recorded or estimated doses of 0.5 or more Gy or Sv without regard to geographic restrictions.
3) Create a separate file; some may be duplicated in the cohort.

Task 8 Investigate Dosimetry Sources and Needs

1) Identify available data on physical dose estimates and methodologies.
2) Determine what additional efforts would be needed to provide physical dose estimates ny physical dose reconstruction and by ESR.

Task 9 Study Tasks of Clean-up Workers

Collect and analyze available information on type of work, working conditions, working environment, date of exposure and duration of exposure.

Task 10 Make Physical Dose Estimates for 20 Workers

For a representative sample of 20 workers, experiment with available methods of physical dose reconstruction.

Task 11 Inventory Questionnaire Data

Prepare an inventory of existing questionnaires and evaluate them for completeness and sufficiency for dose estimation.

Task 12 Estimate Need for New Questionnaire Effort

1) Determine whether a new instrument will be required for personal interviewing in Phase II and, if it will be, provide a draft.
2) If an extensive interviewing process is contemplated for Phase II, make tentative plans for its accomplishment.

Task 13 Investigate Tooth Sampling

The sampling situation will be investigated with a view to determining how best to obtain tooth enamel on members of the subcohort and on cases of leukemia and lymphoma.

Task 14 Establish EPR Dosimetry laboratory

1) Strengthen existing facilities with necessary equipment and supplies.
2) Continue methodologic research, including exchange of samples with reference laboratories.

Task 15 Establish Biodosimetry Laboratory

1) Strengthen existing facilities with necessary equipment and supplies.
2) Perform necessary training.

Task 16 Perform FISH Tests on Bloods

In support of the effort to compare the results of various methods of dose reconstruction (cf Task 19), independently perform FISH tests on about 50 subjects whose doses have been estimated by other means.

Appendix 1: List of Tasks (cont.)

Task 17 Validity of Biological Dosimetry

Blood samples obtained prior to therapy for (both exposed and non-exposed) leukemia and lymphoma patients will be investigated by cytogenetic methods, including FISH, to determine whether cytogenetic dose estimation is compromised by the presence of disease.

Task 18 Accumulate Tissues for Banks

1) Study possibilities for accumulating tissue and begin creating a tissue bank for patients with leukemia and lymphoma.
2) Evaluate existing procedures and equipment for archiving teeth and derivative material.

Task 19 Compare Various Dose Estimates

1) Prepare a formal design for comparing doses obtained independently by environmental dose reconstruction, EPR and FISH for 50 workers.
2) Locate and bleed the 50 workers for FISH determinations (cf Task 16).
3) Analyze the results statistically in pairs of methods and, to the extent possible with the numbers available, for all three methods simultaneously.

Task 20 Update 1987-1997 Leukemias and Lymphomas

1) Search for leukemia and lymphoma cases among men aged 20-60 in the records of the Hematological Department of the Dnipropetrovsk Oblast Hospital, the oblast Oncologic Dispensary, and the dispensary branch for monitoring Chornobyl victims. Note any indication of Chornobyl status.
2) Learn what diagnostic materials suitable for review have been retained and how a diagnostic review might best be organized.

Task 21 Link Leukemias/Lymphomas to Registry

1) Search the State Registry for the cases of leukemia and lymphoma found in Task 20.
2) Evaluate the oblast hematologic services as the primary source of information on leukemia and lymphoma among clean-up workers, 1987-1997.

Task 22 Diagnostic Review

1) Representative samples of the leukemias and lymphomas, perhaps 50 and 20 cases, respectively, for the period 1987-1997, would be selected.
2) The original case material would be reviewed by expert hematologists and pathologists from both countries according to a predetermined protocol.

Task 23 Investigate Ascertainment of Other Diseases

1) The records of the hematology departments of the Dnipropetrovsk oblast will be searched for leukemia-related diagnosis (i.e., myelodysplasia, polycythemia, vera, thrombocythemia, aplastic or hypoplastic anemia, and myelofibrosis) and any indication of Chornobyl status will be noted.
2) The resulting list will be searched in the Chornobyl Registry for the presence of these cases in the Registry.

Appendix 1: List of Tasks (cont.)

3) A decision will be made as to the feasibility of studying these diagnoses in the cohort for 1987-1997.

Task 24 Meeting with Hematologists, Oncologists and Pathologists

1) Early in the project, representatives of the Research Center for Radiation Medicine will hold a one-day orientation with 1-2 key hematologists from each of the six study areas to describe the plans for Phase I and Phase II.
2) Before interviews begin and blood is drawn, representatives of the Research Center for Radiation Medicine will meet with hematologists and other personnel of the Dnipropetrovsk oblast to provide detailed information about such study procedures as interviewing, drawing, processing and shipping bloods, diagnostic criteria and informed consent.

Task 27 Obtain and Process Pre-Treatment Blood, Marrow

1) Pre-treatment blood and bone marrow from at least three adult patients in Dnipropetrovsk with leukemias or related disorders (male or female) and one with lymphoma (with fresh tissue) will be processed in accordance with Appendix 3 of the protocol.
2) Lacking adequate material from Dnipropetrovsk, any deficit may be filled by material from patients in Kiev.

Task 29 Explore High-Dose Sample Size

From the information obtained in Task 7, a determination will be made as to the adequacy of the size of the sample in light of the objectives of the protocol.

Task 30 Identify, Trace and Interview 40, Bleed 20

1) Select two representative samples of about 20 workers, each from the State Registry in Dnipropetrovsk.
2) One sample is to be located and interviewed to obtain information needed for dose estimation and to obtain a brief medical history.
3) The other sample is to be interviewed and bled.
4) The general and medical information obtained is to be compared with information in the State Chornobyl Registry.
5) The bloods are to be shipped to Kiev and processed in accordance with Appendix 3 of the protocol.

APPENDIX 2

TABLES

Appendix 2
Table A 2.1 (Section 2.2, p.12)

Structure of the Information Found in the State Registry (SR)

Semantics of Table	Semantics of Field	Details
Main Registered information	Systemic number	N of the person registered in the SR
	Date of registration	
	Date of departure	
	ZKPO code	General Classifier of an Enterprise and a Branch given by the medical institution the information coupons are from.
	Additional code LPU	Makes up 6 positions where 1-2 means code of the oblast. 3-4 – code of this oblast district. 5-6-is code of the medical institution in the district.
	District number	Two-digital code to designate N of the district medical institution a liguidator has routine medical examinations
	Index card number	N of the patient"s medical record in the districts
	Surname	
	Name	
	Patronymic	
	Sex	1 is male / 2 is female
	Date of birth	
	Observation category	Takes on values 1,2,3,4: 1-persons having radiation sickness 2-adults from 25 Gy pregnant women and children from 5 Gy 3- adults from 10-2525 Gy pregnant women and children from 1-5 Gy 4-Others / Over 5-10 GY 5- Others < 5 GY
	Registration group	Takes on values 1,2,3,4: 1-a liguidator 2-evacuees 3-residents of the contaminated territories 4-children of the parents from group 1-3
	Victim category	Takes on values 1,2,3,4 given to each liguidator according to the Law on the Stats of a liguidator
	Victim certification series	
	Victim certification number	
	Date sertification issued	
	Office that issued the sertification	
	Zip code of place of residence	
	Oblast code of place of residence	
	District code of place of residence	

	Street, house, building, apartment	
	Type of clinical examination and treatment in current year	
Influence of FACTOR before input to the SR	Influence of factor 1 - - - - - 4	System of reference books according to ORDER N 550
Diagnoses of chronic illnesses that were detected before 26.04.86 or before the time of entering the zone	Systemic number	N of the person registered in the SR
	Diagnoses code 1 - - -5	System of reference books according ICD-9.
Profession information	Systemic number	N of the person registered in the SR
	Branch before Chernobil accident	System of reference books
	Profession befor Chernobil accident	System of reference books
	Industrial work recor	
	Branch after Chernobil accident	System of reference books
	Profession after Chernobil accident	System of reference books
Presence in the isolation zones	Systemic number	N of the person registered in the SR
	Zip code of nearest settlement	
	Settlement	
	Purpose for pr esence in zone	1- 1-Permanent resident 2-is permanent work 2- 3-official trip 3- 4-is agricultural work 4- 5-is other
	Date entered zone	
	Date left zone	
Dosimetry data	Systemic number	N of the person registered in the SR
	Thyreoid Dose Level	
	External radiation dose	
Code card	Systemic number	N of the person registered in the SR
	GCEB(ZKPO) code	
	Additional code on card	
	District number on card	
	Index card number on card	
	Date the card filled out	
	Invalidism group	
	Date transferred to invalidism	

Diagnosis for transfer to invalidism	
Group of dispensary clinical and diagnostic service	Takes on values 1,2,3,4,5,6,7: - - healthy - - is practically healthy - - is diseased(chronic disease compensation stage - - is diseased(chronic disease sub-compensation stage - - is diseased(chronic disease de-compensation stage - - died this year - - is out of file
Date of death	
Cause of death	Code of the disease found to be cause of the death
Social group	System of the reference books values from 1 to 9: - - is a worker - - is agricul/worker - - is an employee - - is a service pensioner - - a disability pensioner - - pupil - - student - - housewife 9- others
Field	System of reference book. Takes on a value from 1-16. 1-industry 2-agriculture 3-construction - - - - - - - - 16- others
Profession	System of reference books.Takes on a value from 1-24. - - engineer - - technician and so on - - _____ 24 - ---------- others.
Examination at Whole Body Counter (WBC)	

	Diagnosis of illness 1 - - - - 4, for which reason victim is under dispensary observation	System of reference books according ICD-9.
	Diagnosis of illness 1 - - -4 first detected in the current year and that which is undergoing dispensry observation	System of reference books according ICD-9.
	Diagnosis of other illness 1 -- - - --4 first detected in the current year	System of reference books according ICD-9.
	Influence of harmfactor 1 - -- - - 4	System of reference books according to ORDER N 550

Appendix 2
Table A 2.2 (Section 2.3, p. 13)

Distribution of Liquidators Registered on Chornobyl State Registry by Sex, Age and Year of Service

1	Year of birth	Sex	Year of service							
			1986	1987	1988	1989	1990	1 9 8 6 - 1990	Unknown	At all
1	2	3	4	5	6	7	8	9	10	11
1	1900-1925	M	276	17	3	1	0	297	198	495
		F	118	9	3	1	0	131	44	175
2	1926-1930	M	1464	164	22	6	5	1661	803	2464
		F	167	29	6	2	1	205	87	292
3	1931-1935	M	2227	336	70	19	10	2662	1293	3955
		F	470	81	6	4	0	561	218	779
4	1936-1940	M	6038	871	153	54	25	7141	3325	10446
		F	1302	225	27	8	8	1570	524	2094
5	1941-1945	M	5855	2061	696	200	37	8849	2759	11608
		F	793	132	25	3	3	956	382	1338
6	1946-1950	M	12870	7155	4210	2439	647	27321	5238	32559
		F	1106	162	26	11	4	1309	513	1822
7	1951-1955	M	18225	10856	6940	4046	1084	41151	6273	47424
		F	924	138	21	5	3	1091	413	1504
8	1956-1960	M	22045	10625	4787	3890	1269	42616	6188	48804
		F	774	137	27	6	0	944	364	1308
9	1961-1965	M	19885	8310	535	244	100	29074	4480	33554
		F	764	133	22	6	5	930	363	1293
10	1966-1970	M	2614	1063	248	133	50	4108	1205	5313
		F	427	129	15	9	1	581	184	765
11	Total	M	91499	41458	17664	11032	3227	164880	31762	196642
		F	6845	1175	178	55	25	8278	3092	11370

Appendix 2
Table A 2.3 (Section 2.3, p.13)

Distribution of Liquidators Registered on Chernobyl State Registry by Reported Official External Dose and Year of service

'	Dose (RAD)	Year of service							At all
		1986	1987	1988	1989	1990	1986-1990	Unknown	
1	Up to 4,9	4115	3985	10560	8514	2420	29594	16	29610
2	5-14.9	7473	20737	3369	938	177	32694	7	32701
3	15-24.9	21486	5479	114	34	4	27117	3	27120
4	25-34.9	6941	411	26	13	1	7392	3	7395
5	35-44.9	124	8	4	7	1	144	0	144
6	45-54.9	46	7	5	17	2	77	1	78
7	55-64.9	41	7	4	0	0	52	2	54
8	65-74.9	19	5	0	0	0	24	1	25
9	75-84.9	11	2	1	1	0	15	0	15
10	85-94.9	5	11	0	0	1	17	0	17
11	95-104.9	13	6	3	0	0	22	0	22
12	Up to 105	40274	30658	14086	9524	2606	97148	33	97181
13	105 and more	99	22	16	6	4	147	1	148
14	At all	40373	30680	14102	9530	2610	97295	34	97329
15	Unknown	57947	11948	3736	1557	642	75830	34853	110683
16	Total	98320	42628	17838	11087	3252	173125	34887	208012

Appendix 2
Table 2.4 (Section 2.3, p. 13)
Distribution of Liquidators Registered on Chernobyl State Registry by Year of Registration and Year of Service

'	Year of service	Se	Yeare of registration														At all
			1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	
1	1986	M	122	55267	2187	1608	4671	9204	7647	5260	7801	3805	3351	10972	2345	86	114326
		F	8	3092	133	182	579	1227	903	539	838	388	436	1585	327	15	10252
2	1987	M	0	17797	8265	2344	2858	4317	2745	1657	1930	1043	888	1650	692	11	46197
		F	0	213	67	31	150	319	170	143	191	77	67	94	44	0	1566
3	1988	M	0	0	4092	6579	2263	2292	1219	767	851	587	452	715	317	8	20142
		F	0	0	7	15	24	78	28	18	36	10	14	22	6	0	258
4	1989	M	0	1	0	3906	3738	1547	978	513	522	418	283	398	229	5	12538
		F	0	0	0	3	6	11	22	5	19	6	4	12	2	0	90
5	1990	M	0	0	0	0	1970	602	359	215	190	204	118	263	105	0	4026
		F	0	0	0	0	8	8	3	4	16	12	6	25	9	0	91
6	1986-1990	M	122	73065	14544	14437	15500	17962	12948	8412	11294	6057	5092	13998	3688	110	197229
		F	8	3305	207	231	767	1643	1126	709	1100	493	527	1738	388	15	12257
7	After 1990	M	0	0	0	0	0	28	25	16	17	8	2	6	3	0	105
		F	0	0	0	0	0	2	7	0	2	0	0	0	0	0	11
8	At all	M	122	73065	14544	14437	15500	17990	12973	8428	11311	6065	5094	14004	3691	110	197334
		F	8	3305	207	231	767	1645	1133	709	1102	493	527	1738	388	15	12268
9	Unknown	M	0	265	40	26	24	26	36	555	649	1687	3895	1838	1176	145	10362
		F	0	89	1	4	8	3	4	50	44	189	304	275	159	19	1149
10	Total	M	122	73330	14584	14463	15524	18016	13009	8983	11960	7752	8989	15842	4867	255	207696
		F	8	3394	208	235	775	1648	1137	759	1146	682	831	2013	547	34	13417

Appendix 2
Table A 4.1 (Section 4.2, p. 16)
Completeness of Selected Variables For the Cohort

Field Name	Description	No. Of Entries in the Field	Completeness of the Variable (%)
SYS_N	Systemic number	100110	100.0
D_KART	Date of registration	100110	100.0
DAT_OUT	Date moved out of the oblast	438	0.44
N_UCH	No of the medical area	100087	99.98
FAM	Last name	100110	100.0
NAM	First name	100110	100.0
OTCH	Patronymic	100108	100.0
D_ROZD	Date of birth	100110	100.0
KAT_NAB	Category of medical follow-up	100110	100.0
KAT_POST	Category of liquidator	28702	28.67
SER	Serial No of the Document	29206	29.17
N_DOK	No of the Document	29745	29.71
INDEX	Zip code	99500	99.39
OBL	Oblast	93347	93.24
REG	Raion	93346	93.24
DOP_LPU	Code of the medical facility	55365	55.30
N_PUNKT	Code of the place of residence	78315	78.23
ADRES	Address	90825	90.73
T_DISP	Talon from annual check-up	96335	96.23

Appendix 2
Table A 4.2 (Section 4.2, p. 16)
Official Dose Distribution For the Cohort

Distribution of the liquidators of the Cohort file registered in the SR of Ukraine according to the officially registered dose of external exposure allowing for all those registered (as to data at the moment of the query)

1	Dose (Rad)	Year of participation in the emergency works						Unknown	Total
		1986	1987	1988	1989	1990	1986-1990		
1	2	3	4	5	6	7	8	9	10
1	Before 5	1463	1569	4888	4460	911	13291	11	13302
2	5 – 14.9	2025	10499	1716	355	40	14635	10	14645
3	15 – 24.9	8715	2579	48	14	2	11358	7	11365
4	25 – 34.9	4138	265	7	8	1	4419	4	4423
5	35 – 44.9	66	4	3	3	1	77	0	77
6	45 – 54.9	30	5	4	8	0	47	1	48
7	55 – 64.9	29	4	2	0	0	35	2	37
8	65 – 74.9	17	2	0	0	0	19	1	20
9	75 – 84.9	7	0	1	0	0	8	0	8
10	85 – 94.9	1	6	0	0	0	7	0	7
11	95 – 104.9	3	2	1	0	0	6	0	6
12	Before 105	16494	14935	6670	4848	955	43902	36	43938
13	105 and more	58	9	6	3	0	76	0	76
14	Total	16552	14944	6676	4851	955	43978	36	44014
15	Unknown	44463	6696	2468	1486	450	55563	481	56044
16	Total	61015	21640	9144	6337	1405	99541	517	100058

Appendix 2
Table A 4.3 (Section 4.2, p. 16)
Distribution by Age Group and Year Started Work As Liquidators

Distribution of the liquidators of the Cohort file registered in the SR of Ukraine according to the age groups, years of participation in the emergency works as to Dec.1, 1998, allowing for all those registered

1	Year of birth	Year of participation in emergency works							
		1986	1987	1988	1989	1990	1986-1990	Unknown	Total
1	1900-1925	294	16	3	2	0	315	3	318
2	1926-1930	1507	119	14	3	1	1644	6	1650
3	1931-1935	2309	181	40	12	6	2548	19	2567
4	1936-1940	6159	613	120	42	21	6955	23	6978
5	1941-1945	4999	1074	355	133	23	6584	29	6613
6	1946-1950	9332	3905	2218	1338	281	17074	84	17158
7	1951-1955	11814	5938	3588	2310	439	24089	98	24187
8	1956-1960	12935	5467	2431	2268	548	23649	147	23796
9	1961-1965	10034	3819	278	148	54	14333	91	14424
10	1966-1970	1632	508	97	81	32	2350	17	2367
	Total	61015	21640	9144	6337	1405	99541	517	100058

Appendix 2
Table A 4.4 (Section 4.2, p. 16)
Distribution by Oblast of Residence

Distribution of the liquidators of the Cohort file according to the residence
(as to the data of SR on Dec.,1, 1998)

Oblast code	Region	Year of participation in the emergency works							Total
		1986	1987	1988	1989	1990	1986-1990	Unknown	
04	Dnipropetrovsk	8878	5349	2275	1597	126	18225	252	18477
05	Donetsk oblast	9513	6058	2526	1846	444	20387	46	20433
10	Kyiv oblast	7864	425	49	11	0	8349	0	8349
18	Sumy oblast	4503	3498	1462	993	345	10801	117	10918
20	Kharkiv oblast	7515	4848	2149	1584	409	16505	35	16540
26	Kyiv city	2274	1462	683	306	81	25274	67	25341
	Total	6101	21640	9144	6337	1405	99541	517	100058

Appendix 2
Table A 5.1 (Section5.3, p. 17)
Search in the State Registry for Dnipropetrovsk Clean-Up Worker Cases of Leukemia and Lymphoma Which Had Been Identified From Various Sources

Diagnosis	Number Registered in Various Sources				Total identified from all sources	Cases recorded in State Registry	Improperly recorded cases in State Registry
	Dept. for Support of Medical Victims	Oblast Cancer Registry	Oblast Hematology Dept.	Center for Radiation Medicine			
Leukemia	9	10*	7	4	12**	8**	11
Lymphoma	7	4***	1	0	7	7	16
Total	16	14	8	4	19	15	27

* 3 of the 10 cases reported as leukemia by the cancer registry eventually proved to be leukemia-related disorders and were not included in the Chernobyl State Registry.

** At least one case of leukemia and possibly three others (the three cases from the Cancer Registry as noted above) were not registered in the Chernobyl State Registry. Note that the Cancer Registry does not report directly to the Chernobyl State Registry.

*** One of the four cases reported by the Cancer Registry as a lymphoma probably is a case of leukemia.

Appendix 2
Table A 6.1 (Section 6, p. 19)
Number and Type of Hematologic Disease Cases Proposed for Random Selection from Kiev City and Five Oblasts for Expert Panel Review, January 1999.

Diagnosis	Number of Cases Reported from Each City or Oblast
Chronic myelogenous leukemia	2
Chronic lymphacytic leukemia	2
Acute leukemia (any type)	5
Myelodysplasia	2
Myelofibrosis/hypoplastic/aplastic anemia	2
Non-Hodgkin's lymphoma	3
Hodgkin's Disease	2
Multiple Myeloma	2
Total	20

Request was for reasonably equitable distribution of cases for 3 specific time intervals between 1987 and 1998 from the general male population, ages 20-60 at time of diagnosis.

Appendix 2
Table A 6.2 (Section 6, p.20)

Retrievable Bone Marrow Slides of Randomly Requested Cases* of Leukemia, Lymphoma and Related Disorders from Kiev City and Five Oblasts for Three Time Periods for Expert Panel Review, January 1999.

Period	Leukemia		Lymphoma		Related Disorders		Total	
	#cases with slides/#cases	%	# cases with slides/#cases	%	#cases with slides /#cases	%	# cases with slides /#cases	%
Early (1987-90)	4/17	24	2/10	20	1/5	20	7/32	22
Middle (1991-94)	5/7	71	1/6	17	1/1	100	7/14	50
Late (1995-98)	11/19	58	3/10	30	4/7	57	18/36	50
Total (1987-98)	20/43	47	6/26	23	6/13	51	32/82	40

* - # Cases of males in the general population, ages 20-60 at time of diagnosis.

Appendix 2
Table A 6.3 (Section 6, p.20)

Retrievable Medical Records of Randomly Requested Cases* of Leukemia, Lymphoma and Related Disorders from Kiev City and Five oblasts for Three Time Periods for Expert Panel Review
January 1999

Period	Leukemia		Lymphoma		Related Disorders		Total	
	#cases with records/#cases	%	# cases with records/#cases	%	#cases with records /#cases	%	# cases with records /#cases	%
Early (1987-90)	9/17	53	5/10	50	2/5	40	16/32	50
Middle (1991-94)	4/7	57	2/6	33	1/1	100	7/14	50
Late (1995-98)	15/19	79	6/10	60	5/7	71	26/36	72
Total (1987-98)	28/43	65	15/26	50	8/13	62	51/82	62

* # Cases of males in general population, ages 20-60 at time of diagnosis.

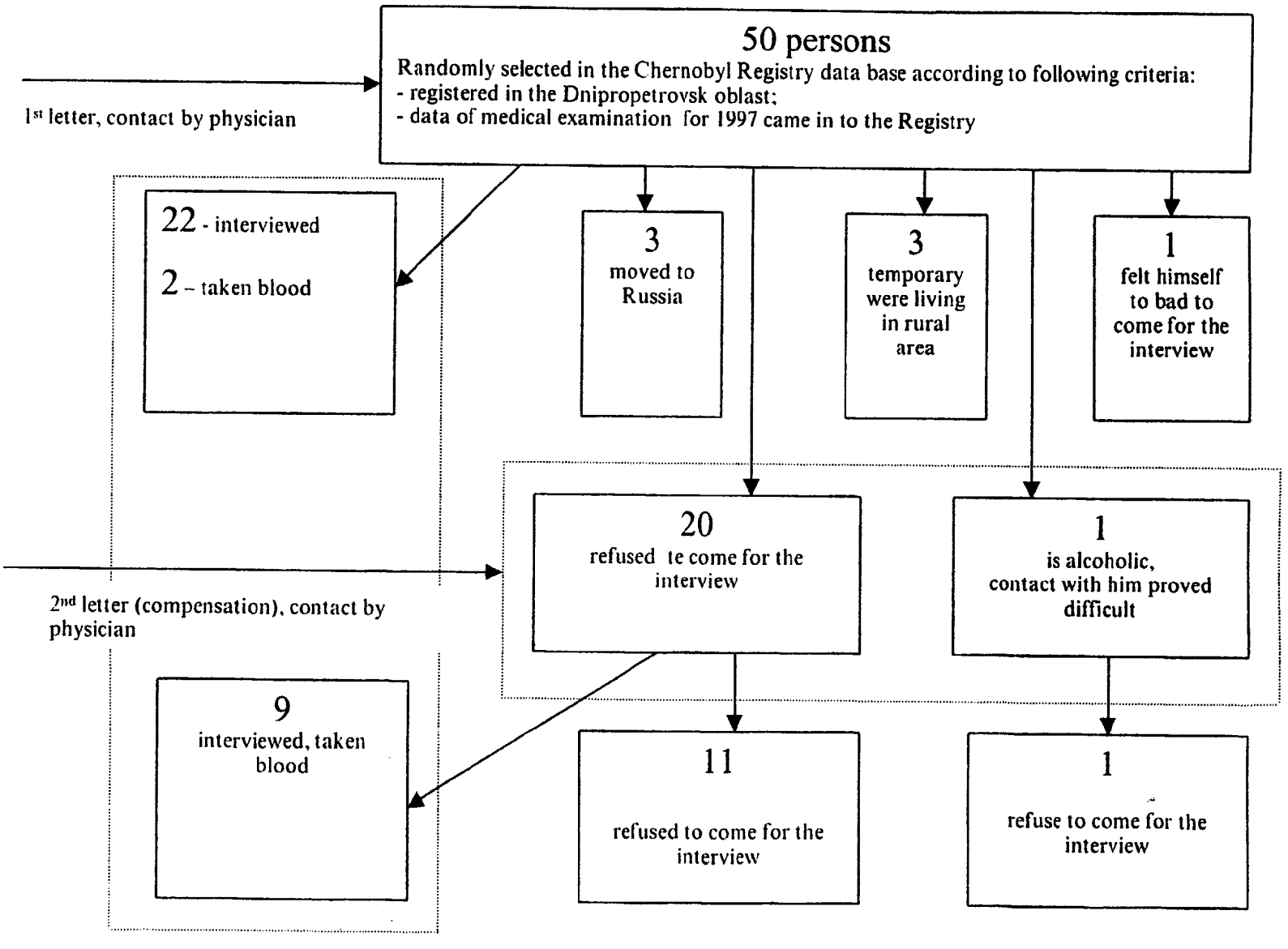
Appendix 2
Table A 6.4 (Section 6, p. 22)

Availability for Review of Bone Marrow Slides and Medical Records from Liquidators with Leukemia in Four Oblasts, 1987 – 1998

Oblast	Slides		Medical Records	
	# with slides / Total #	%	# with slides / Total #	%
Dnipropetrovsk	12/18	67	18/18	100
Cherkassy	5/5	100	5/5	100
Chernihiv	7/17	41	9/17	53
Karkiv	3/12	25	10/12	83
Total	27/52	52	42/52	81

Appendix 2
Table A 8.1 (Section 8.2, p. 26) Scheme

Scheme of the engagement for the interview and taking blood



Appendix 2

Table A 8.2 (Section 8.2, p.26) Instructions

Instructions Manual for interviewing and taking blood

1. Sampling of the persons for interviewing is accomplished by the epidemiologic group of the Project (responsible persons - Dr. Boris Ledoshchuk, tel.416-69-34; Dr. Gennady Kartushin, tel. 450-92-14). The sampling is carried out using method of random numbers among the male clean-up workers registered in the State Registry in the Dnipropetrovsk oblast, the number being 40 persons. 30 of them were selected from among the patients having data as to their routine physical examination during 1997 in the State Registry, and 10 patients from among those " lost-to-follow-up ", i.e. the persons having no information as to their physical examination during 3 and more years.

2. The epidemiologic group makes the list of the persons selected indicating surname, name, patronimic, date of birth, home address, codes of the medical institution where the clean-up worker is under surveilance, and passes it to the head of the department for medical support of the Chernobyl victims Chekmareva T. tel. (0562)47-16-97, 46-84-46.

3. T.Chekmarevs is responsible for interviewing .

4. For the interview a questionnaire will be used compiled for similar investigations under WHO in Russia.

5. The place for interviewing is the Oblast Clinical Hospital.

6. The clean-up workers listed are invited for the interview:

- by the physician responsible for the victims of the territorial polyclinic;
- in written form (the text of the letter is presented below).

Dear.....,

You are invited to take part in the Ukrainian-American Programme of examining participants of liquidating consequences of the Chernobyl accident.

The aim of this Programme is to follow-up physical condition of the mostly suffered part of the population of Ukraine revealing blood diseases in this group at early stages.

With your consent a detailed study will be made of your laboratory data during recent years in dynamics; some additional blood examinations will be repeated or done, if necessary. A questionnaire will be filled in with your help which will make it possible to revive in detail the period of emergency works and possibly, your dose exposure.

In Dnipropetrovsk oblast departments of the oblast clinical hospital No.4, hematologic department of the city hospital No.3 (Dnipropertrovsk city), units of the district outpatient clinics of the oblast are involved in the Programme performance.

The head of the dispensary department for medical support of the Chernobyl victims at the oblast clinical hospital Chekmareva T.I. will meet with you at the time convenient for you which will be agreed with you by the responsible physician.

Thank you in advance for your interest and participation in the Programme.

We hope that with minimum waste of your time it will be of use for you and will help us to coordinate some issues of rendering hematologic help.

Chekmareva T.I.,
Head of the dispensary department for medical support
of the Chernobyl victims

7. Chekmareva T. With a liquidator's consent designs a schedule for interviewing allowing for the fact that the persons to be bled must be invited in the afternoon on my working day except Friday which is connected with the necessity of durable transportation and futher processing of the blood .

8. The interview is conducted in accordance with the interview's operating manual and recommendations given at the training seminar. The problems arising during the interview are discussed by T.Chekmareva with the representative of the epidemiologic group with Gudzenko N.

9. The filled in forms of the questionnaires are forwarded by T.Chekmareva to the epidemiologic group at thr RCRM.

10. 20 liquidators from among those interviewed must be bled, the blood being transferred to the RCRM.

11. After interview the clean-up workers are suggested to have their blood investigated.

12. Prior to bleeding , a clean-up worker is proposed to get acquainted with the informed consent (the text is presented below) for blood examination and to sign it. No bleeding is done without his consent.

Research Center for Radiation Medicine

Information Concent

Study of leukemia and other hematological deseases in liquidators following the Chornobyl accident in Ukraine

Family name, first name and patronimic _____

Date of birth_____

I know that the Research Center for Radiation Medicine of Academy of Medical Sciences of Ukraine and National Cancer Institute (USA) are engaged in the study of hematologic deseases which may develop in the liquidators following the Chornobyl accident. With this purpose I am asked to give some amount of blood (20 ml) which will be treated during some days, frozen and analyzed later to reveal any possible radioinduced changes. During blood removal from vein light pain, insignificant bleeding or bruise in the place of needle puncture are possible. I am also asked to answer some questions concerning my health, my profession and character of my work in the 30-km zone following the Chornobyl accident.

This as well as other information will enter my medical record and won't be disclosed exept for in case of extreme need. The resultsmay be used for medical report without mentioning my name.

I know that my participation in this work is voluntary and if refuse now or in future it won't affect the medical assistanse I get at all.

If I have some questions as to my participation in this work I can get in touch with Dr. Gaydukova Svetlana Nicolaevna, head of the chair of hematology at the Kyiv Medical Academy for Postgraduate education on the phone 211-89-39.

I got acquainted with this document and give my consent to participate in the work before mentioned.

Date_____ Signature of participant_____

Physician _____

13. All possible liquidator's reactions as to the suggestion for bleeding (refusal to donate blodd, refusal to sign the letter, etc.) are registered in an accompanying document in the form provided by the epidemiologic and hematologic groupd prior to the beginning of bleeding.

14. The fact of bleeding is to be underlined .

15. If the liquidator is compensated for financial losses due to loss of working time or transportation, he will have to foll a receipt

A receipt

I _____

Passport # _____

Issued _____

Address _____

Participated in the Ukrainian-American study of hematologic deseases which may develop in the liquidators following the Chornobyl accident..

Wastes of working time and transport expenses were compensateed to me in the sum of

_____ grivnas.

Date_____ Signature _____

16. Bleeding is performed in the special room.

17. The responsible person for the blood procurement and its transfer to the RCRM is head of the hematologic department of the city hospital in Dnipropetrovsk Kaplan P. Tel. (0562) 58-52-09.

18. To perform bleeding the hematologic group of the RCRM should provide:

- needles and syringes;
- vacutainers heparinized in the necessary quantity;
- portable freezer (2 items);
- stands (2 items);
- forms of informed consent for bleeding and blood investigation (20 items);
- forms of the covering document (20 items).

19. Prior to bleeding the covering document is filled out (presented below) and the vacutainers are marked involving surname, name and patronimic, date and time of bleeding , address, oblast code, liquidator's code).

COVER NOTE

The venous blood sample of a patient taking part in the Ukrainian-American study on leukemia and related diseases in the clean-up workers following the Chernobyl accident in Ukraine

FAMILY NAME_____

NAME_____

PATRONYMIC_____

DATA OF BIRTH _____

HOME ADDRESS: oblast_____

settlement_____

street, house, apartment_____

Amont of the venous blood removed _____

Date of removal _____ Time of removal _____

Name of nurse _____

Signature of nurse _____

20. The amount of blood remove is 20 ml. It is placed in heparinized vacutainers and then put in the stands.

21. The stand is placed in portable freezer.

22. The portable freezer is transferred by the Dnipro train (with the conductor) to Kyiv, the RCRM.

23. The personnel in Kyiv is informed twice:

- on the eve of the planned interviewing with bleeding;
- after transfer of the portable freezer with the samples in the train indicating the carriage and the conductor.

24. Responsible for the samples reception in Kyiv are the following specialists at the RCRM (it is necessary to inform one of them):

- Victor I. Klimenko, tel. 431-98-10;
- Irina S. Dyagil , tel. 431-98-10, 450-47-66;
- Oksana O.Oberenko, tel. 431-98-10, 463-86-40.

25. An empty portable freezer is transferred by the same train and conductor.

26. On receiving the samples the responsible persons aforementioned are obliged to inform P.Kaplan about it within day and night.

27. Samples transfer by train is paid in Kyiv from overhead expenses.

28. The blood is processed and stored in accordance with the requirements of the Protocol at the RCRM.

29. The responsible person for forming samples bank is Irina S.Dyagil.

Appendix 2
Table A 9.1 (Section 9.2, p.27)

Cryopreserved * Biological Samples from Liquidators with Hematologic Disorders

Diagnosis	Number of Liquidators	Tissues in Storage		
		Bone Marrow	Blood Leukocytes	Lymphoma Tissue
Acute Leukemia	7	7	7	-
Chronic Leukemia	4	4	4	-
Non Hodgkin's Lymphoma	2	2	-	2
Thrombocytopenia & Leukopenia	6	6	-	-
Myelodysplasia	8	8	8	-
Total	27	27	19	2

* All samples currently cryopreserved at -70°C.

Appendix 2
Table A10.1 (Section 10.2.1, p. 30)

Number of records with and without dose in the State Registry of Ukraine (SRU) for selected Oblasts

Oblast	Number of records with dose	Number of records without doses
Cherkasy	4963	5796
Chernigov	3027	8797
Dnipropetrovsk	12049	6466
Donetsk	12103	8791
Kharkiv	11967	5082
Kiev	315	31684
Poltava	7423	4681
Zaporizha	619	4086

Appendix 2
Table A10.2 (Section 10.2.1, p. 32)

Characteristics of dosimetric databases for civilian liquidators obtained during Phase I of the study[a].

Name of database	Number of records	Identifiers								Dosimetric data				
		Sur-name	First name	Patro-nymic name	Initials	Year of birth	Date of birth	Passport Number	Postal Address	Number of records with	Number of unique records with	Period of work	Period of dose availa-bility	Organi-zation
CNII	32328	+	+	+	-	13%	-	-	-	19474	18699	52%	86-90	21%
Person1	66470	+	-	-	+	71%	-	+	-	66470	57524	+	86,87	+
PBK2	16416	+	1%	1%	+	0.5%	1%	-	-	16416	14608	-	86,87	+
IDK	51323	+	-	-	+	+	-	42%	-	23382	23249	+	86,87	+
PERSON	39464	+	+	+	-	-	+	47%	+	13619	13584	-	86,87	+
UVOL	57842	+	-	-	+	+	-	22%	-	41780	40730	64%	86,87	+

[a]In this Table, "+" indicates that data are available for all liquidators; "-" indicates that data are not available for any liquidator; percentages are given when data are available for a fraction of liquidators.

Appendix 2

Table A10.3 (Section 10.2.2, p. 34)

Results of the analysis of the databases of instrumental doses obtained during Phase I of the study.

Source of original data	Number of records as transferred to Kiev	Number of records certainly identified as Ukrainian liquidators	Number of records linked with the State Registry of Ukraine	Comments
Database of the Ministry of Atomic Energy and Industry (includes Chornobyl NPP workers)	18699	442	186	Year of birth is missing in 87% of the records. Only 34% of the records contain information on affiliation – the key for identification of Ukrainian liquidators
Operative database of "Kombinat" (RADEK)	57524	27355	7955	
Database of Kurchatov Institute "complex expedition"	14608	7137	8	
Dose database for permanent employees in the 30 km zone	23249	9444	3956	
Database of certificates for employees of the Ministry of Atomic Energy and Industry (includes Chornobyl NPP workers)	15898	8210	1707	This database contains the most of information regarding addresses of liquidators and lacks dosimetry data. However, due to overlapping with other databases, there is a possibility to complete the missing dosimetric fields.
Dose database for the permanent employees in the 30 km zone who were made redundant.	40730	18364	4178	

Appendix 2

Table A10.4 (Section 10.2.2, p. 34)

Degree of consistency between the doses recorded in the SRU and in two of the recently obtained databases (sample of 280 liquidators).

Complete agreement	Agreement within a factor from 1 to 2	Agreement within a factor from 2 to 5	Agreement within a factor from 5 to 10	No agreement within a factor of 10
138	57	24	22	39

Appendix 2

Table A10.5 (Section 10.2.2, p. 35).

Percentage of partisans among respondents to the postal survey.

Oblast	Percentage of "partisans" among respondents
Dnipropetrovsk	86
Donetsk	87
Kharkiv	82
Poltava	91
Zaporija	84

Appendix 2

Table A10.6 (Section 10.3.1, p. 42)

Basic principles of the visual examination of the tooth enamel delivered for dosimetric measurements.

No.	Detailed description of the tooth enamel condition	Score
1.	Teeth roots, remains of teeth roots, complete absence of enamel	1
2.	Insignificant amount of enamel (10-20%), teeth under metal crowns	2
3.	Incisors, canine, entire teeth with little enamel fit for dosimetry	3
4.	Not more than 50% of enamel available (premolars, molars)	4
5.	More than 50% of enamel available	5
6.	Complete crown and root, the tooth was extracted because of paradontosis	6

Table A10.7. Parameters of distributions of SEAD/GS and DEA/GS for professional workers.

Parameter	SEAD/GS	DEA/GS
Mean	2.82	2.84
Standard deviation	3.60	3.30
Geometric mean	1.58	1.69
Geometric standard deviation	2.89	2.79

(Section 10.4.3, p.52)

Table A10.8. Parameters of distributions of SEAD/GS and DEA/GS for sent on mission.

Parameter	SEAD/GS	DEA/GS
Mean	0.17	0.30
Standard deviation	0.16	0.28
Geometric mean	0.11	0.17
Geometric standard deviation	2.86	3.32

(Section 10.4.4, p. 52)

Table A10.9. Distribution of the FISH test subjects by dose groups and independent dosimetry methods. Dose groups were determined on the basis of EPR dose estimates where applicable, otherwise from ADR dose estimates.

	Dose group (dose interval, mGy)				
	0-100	100-250	250-500	500-1000	>1000
Total	7	7	14	12	9
EPR	7	7	13	4	1
ADR	1	5	7	10	9
ODR		2	1		

(Section 10.4.4, p. 58)

Results of FISH vs. EPR doses

#	Group (cGy)	The number of persons	Age			Number of EPR analysis	Dose EPR (cGy)			Frequency reciprocal translocation per 1000 cells		
			Min	Max	Mean		Min	Max	Mean	Min	Max	Mean
1	0,0 – 10,0	7	42	66	54,71	7	8,0	16,7	11,53	3,0	23,0	10,0
2	10,0 – 25,0	7	44	65	54,71	7	15,5	24,0	20,63	9,0	53,0	20,0
3	25,0 – 50,0	14	37	73	53,64	13	30,0	53,0	38,62	11,0	45,0	20,0
4	50,0 – 100,0	12	44	59	52,11	4	57,0	74,0	66,03	11,0	51,0	20,0
5	> 100	9	40	60	50,14	1	142,0	142,0	142,00	17,0	130,0	60,0

Table A.10.10. Comparison of FISH and EPR doses.

(Section 10.4.4, p. 59)

Table A10.7. Parameters of distributions of SEAD/GS and DEA/GS for professional workers.

Parameter	SEAD/GS	DEA/GS
Mean	2.82	2.84
Standard deviation	3.60	3.30
Geometric mean	1.58	1.69
Geometric standard deviation	2.89	2.79

Table A10.8. Parameters of distributions of SEAD/GS and DEA/GS for sent on mission.

Parameter	SEAD/GS	DEA/GS
Mean	0.17	0.30
Standard deviation	0.16	0.28
Geometric mean	0.11	0.17
Geometric standard deviation	2.86	3.32

Table A10.9. Distribution of the FISH test subjects by dose groups and independent dosimetry methods. Dose groups were determined on the basis of EPR dose estimates where applicable, otherwise from ADR dose estimates.

	Dose group (dose interval, mGy)				
	0-100	100-250	250-500	500-1000	>1000
Total	7	7	14	12	9
EPR	7	7	13	4	1
ADR	1	5	7	10	9
ODR		2	1		

Table A.10.10. Comparison of FISH and EPR doses.

Results of FISH vs. EPR doses

#	Group (cGy)	The number of persons	Age			Number of EPR analysis	Dose EPR (cGy)			Frequency reciprocal translocation/per 1000 cells		
			Min	Max	Mean		Min	Max	Mean	Min	Max	Mean
1	**0,0 – 10,0**	7	42	66	54,71	7	8,0	16,7	11,53	3,0	23,0	10,0
2	**10,0 – 25,0**	7	44	65	54,71	7	15,5	24,0	20,63	9,0	53,0	20,0
3	**25,0 – 50,0**	14	37	73	53,64	13	30,0	53,0	38,62	11,0	45,0	20,0
4	**50,0 – 100,0**	12	44	59	52,11	4	57,0	74,0	66,03	11,0	51,0	20,0
5	**> 100**	9	40	60	50,14	1	142,0	142,0	142,00	17,0	130,0	60,0

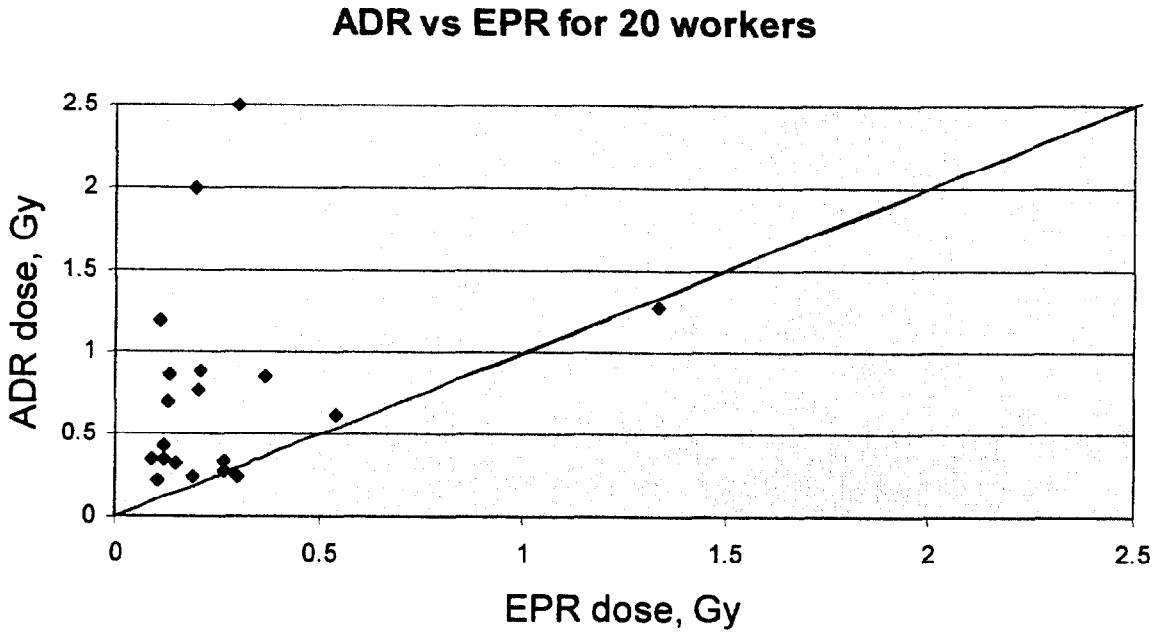


Fig. A10.3. Comparison of ADR and EPR dose assessment for 20 ChNPP workers. ADR value is essentially the "maximum possible dose", although it is conventionally treated in all databases and official documents as a "most likely" value. It is only for the subject with an EPR dose of about 1.4 Gy that the ADR dose was evaluated properly, using realistic values for the "standard episodes".

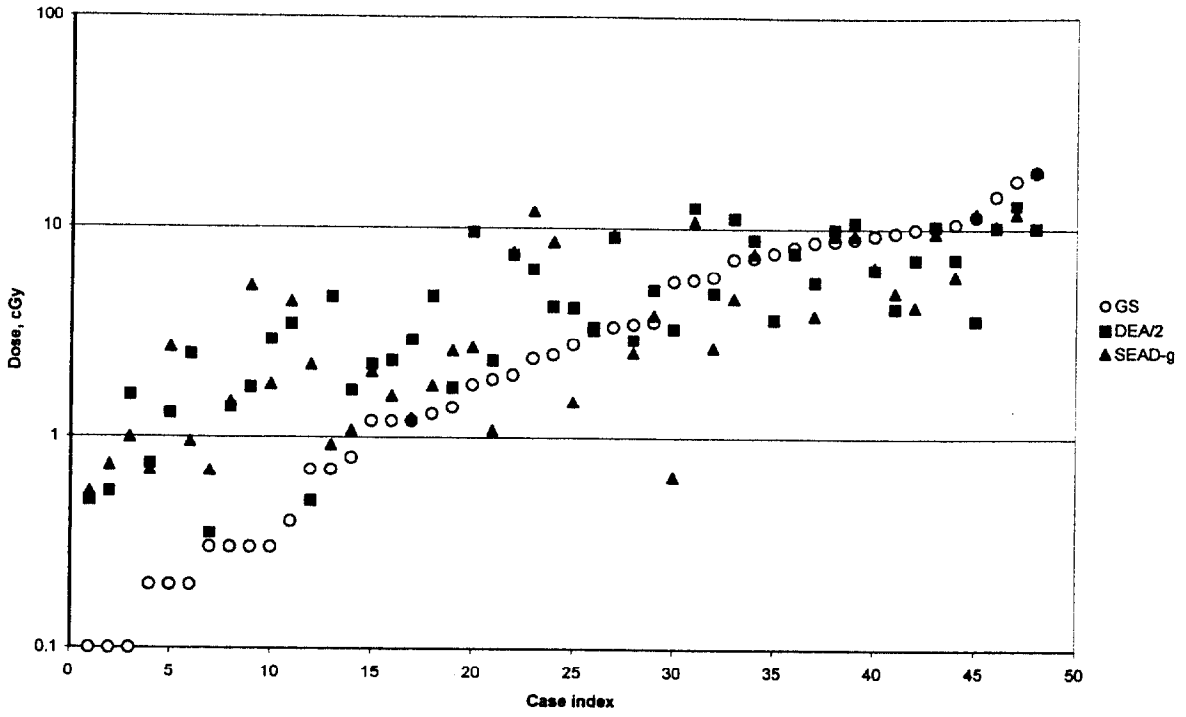


Fig. A10.4. Comparison of "Gold Standard" (in this case – results of individual dosimetric monitoring), SEAD and DEA for professional atomic workers. Cases are sorted by increasing GS dose.

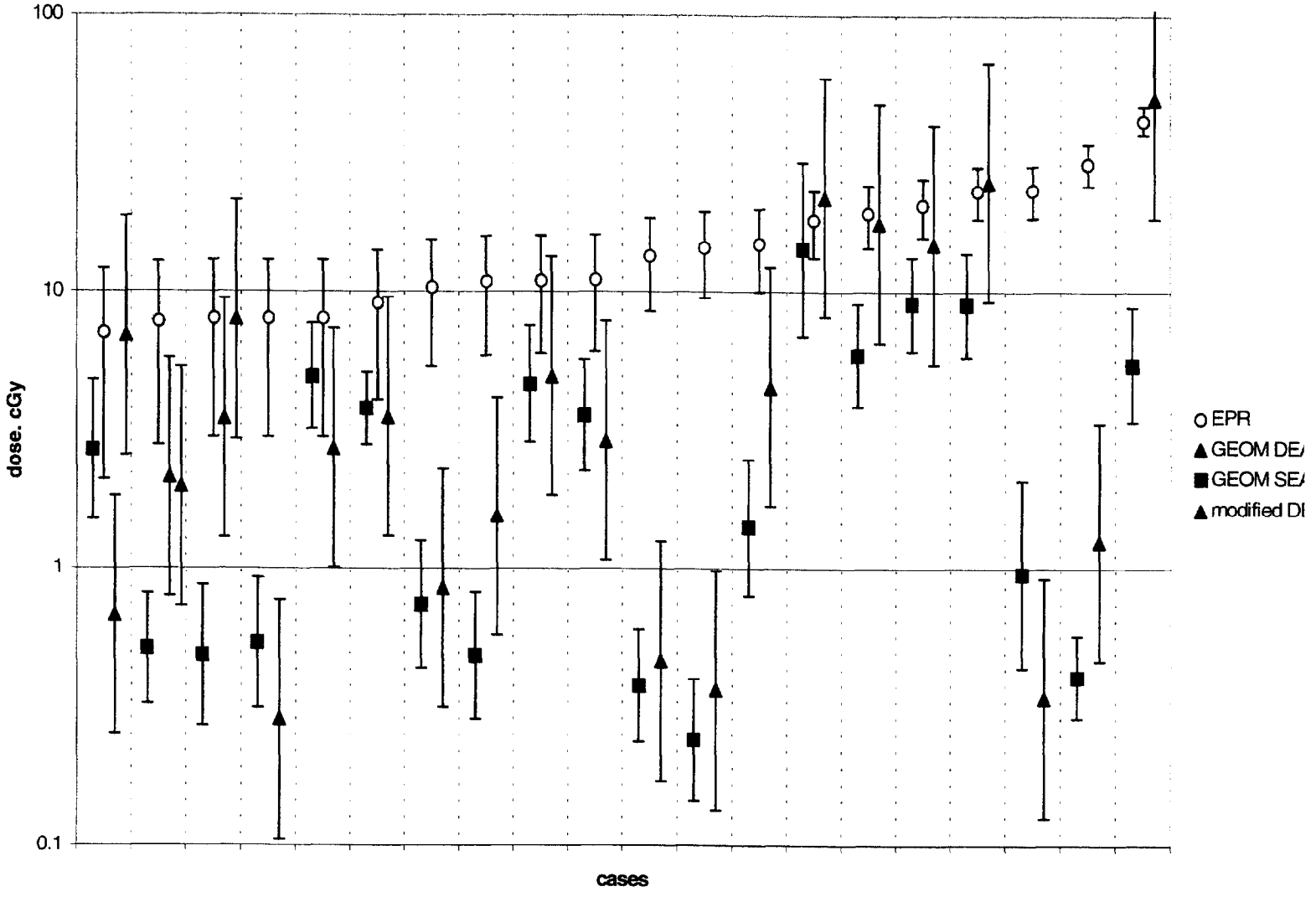


Fig. A10.5. Comparison of EPR (used as "Gold Standard"), SEAD and DEA for sent on mission. Cases are sorted by increasing GS dose. In three cases, DEA evaluations were reconsidered yielding higher doses (modified DEA).

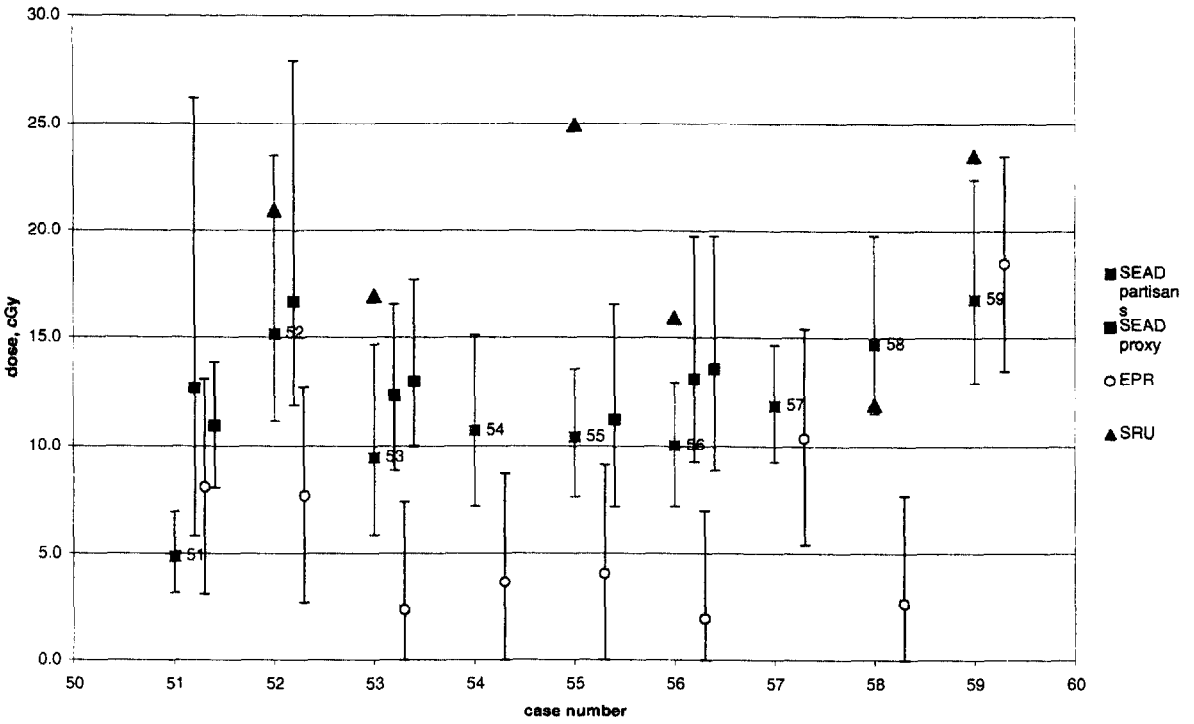


Figure A10.6. Comparison of SEAD and EPR doses for a sample of military reservists. The SEAD dose was either based on the interview of the liquidator himself or on the interview of a proxy. Official dose records, as found in the Chornobyl State Registry are denoted as SRU.

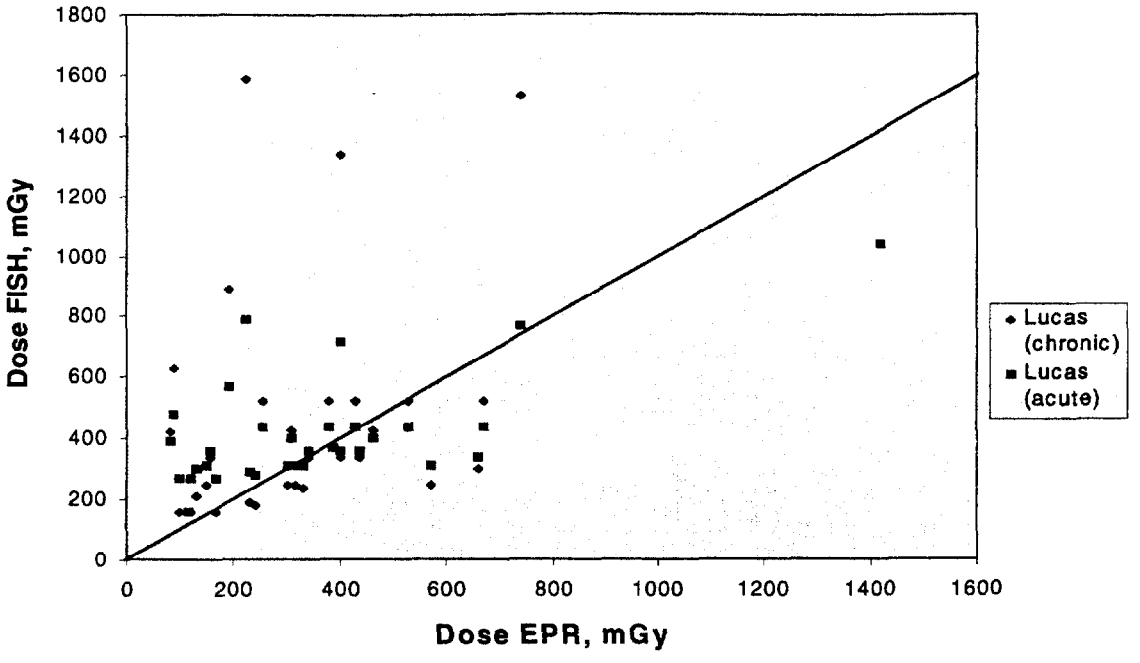


Fig. A10.7. Results of FISH vs. EPR doses.

FISH doses are determined using the same raw data (count of translocation) by applying different calibration formulae. The following calibrations were used:

1. Provided by Lucas for the case of chronic exposure.
2. Provided by Lucas for the case of acute exposure.

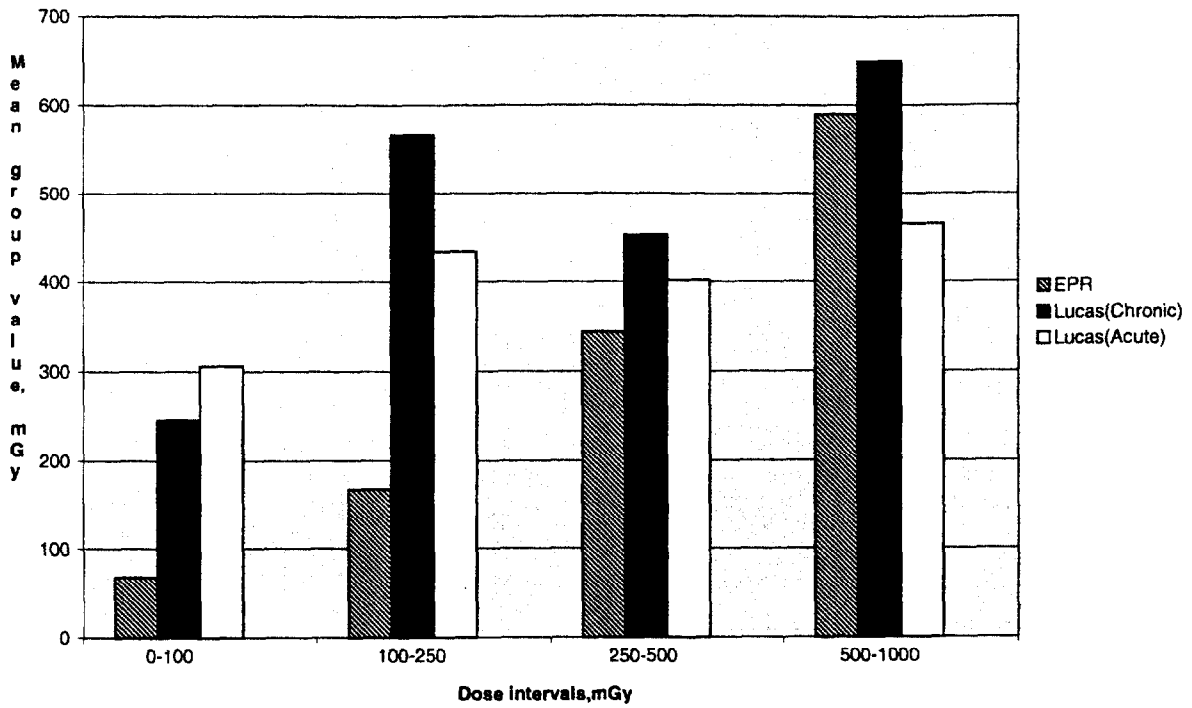


Fig.A10.8 Group averaged dose estimates provided by EPR and by FISH (three calibrations)

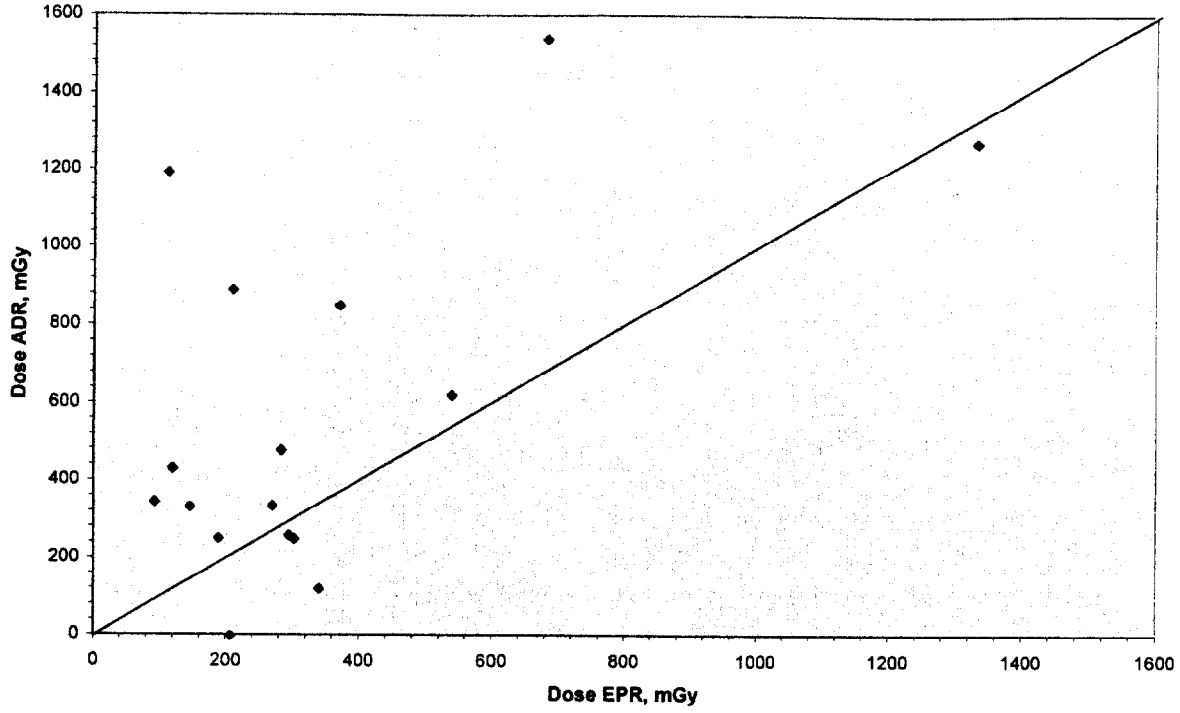


Fig.A10.9. Comparison ADR vs. EPR for FISH exercise subjects

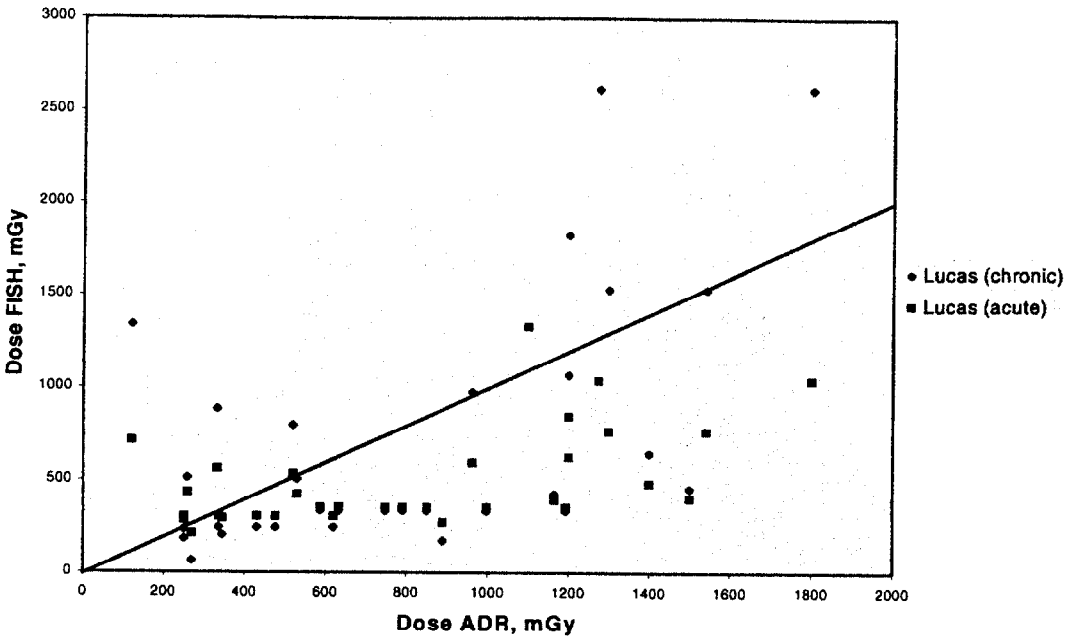


Fig. A10.10. Comparison ADR vs. FISH for FISH exercise subjects

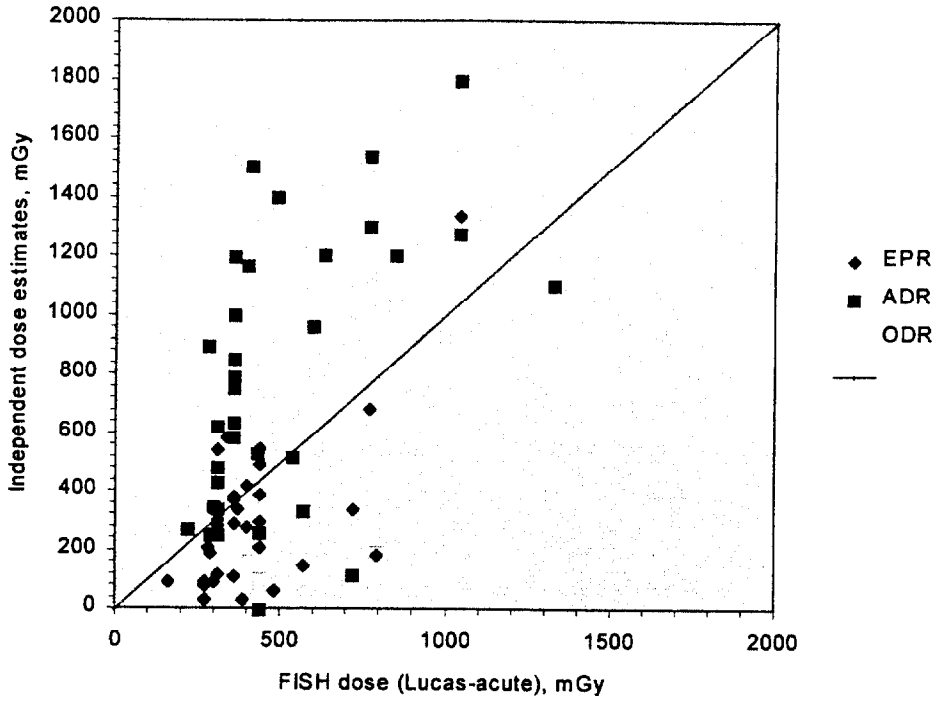


Fig. A10.11. Comparison of FISH doses with EPR/ADR/ODR dose assessments.
32 subjects - FISH vs. EPR
32 subjects - FISH vs. ADR
3 subjects - FISH vs. ODR

APPENDIX 3

DOSIMETRY/EPIDEMIOLOGY QUESTIONNAIRE

Liquidator's identification # /_/_/_/_/

Research study on the liquidators' state of health

Questionnaire

1997-2000

Moscow, Minsk, Kiev, Obninisk,
Lyon, Washington

The following organizations and institutes have participated in creating of this questionnaire:

Belarus

- Belarusian Center of Medical Information Technologies of Management and Economy of Public Health (Minsk)
- Institute for Scientific Research on Hematology and Blood Transfusion (Minsk)
- Institute of Oncology (Minsk)
- State Center of Oncopathology of Thyroid (Minsk)
- Institute for Scientific Research on Radiation Medicine (Minsk)

Russia

- Medical Radiological Scientific Center (Obninsk)
- Institute of Biophysics (Moscow)
- Military Medical Academy (St. Petersburg)

Ukraine

- Chernobyl Nuclear Power Station (Chernobyl)
- Scientific Center of Radiation Medicine (Kiev)

European Commonwealth

- European Commission (Brussels, Belgium)
- International Agency for Cancer Research (Lyon, France)
- Institute of Nuclear Defense and Security (Fontane, France)

USA

- National Cancer Institute (Washington)
- Columbia University (New York)

Information on a liquidator from the Chernobyl Registry

	Chernobyl Registry	Corrections, if any
0.1 Last name	_____	_____
0.2 First name	_____	_____
0.3 Patronymic(middle name)_____		_____
0.4 Date of birth	day/_/_/month/_/_/19/_/_/	
0.5 Identification document (pictured I.D.):		
	1. passport	
	2. military registration card	
	3. other, please specify_____	
	_____	
I.D. code	_____	_____
I.D. #	/_/_/_/_/_/_/_/_/_/_/_/_/	

0.6 Home address

postal index /_/_/_/_/_/_/

oblast (district) _____

region _____

if you live in a city:

city (name)_____

street _____

house # /_/_/_/_/

apartment # /_/_/_/_/

if you live in a village:

village council (local authority) _____

type of village (depending on the number of population, it may have different names)_____

0.7 telephone #: work /_/_/_/_/_/_/_/_/_/_/

home/_/_/_/_/_/_/_/_/_/_/

Last name, first name, patronymic (middle) of the interviewer_____

Date of the interview: day/_/_/ month/_/_/ year 19/_/_/

The interview began at: hour/_/_/ minutes/_/_/

The person being questioned is:

1 liquidator
2 his wife
3 his brother or sister
4 his daughter or son
5 other, specify

If the person who was questioned, is not a liquidator, put his/her last name, fist name and patronymic down _____
and also put down the reason why the liquidator himself was not been able to answer the questions:

1 died
2 too sick to answer questions
3 is on an extended business trip
4 other, specify_____

Do you know names and addresses of colleagues of your husband (brother, father,...), who worked with him in the area of the Chernobyl power station. If yes, please put them down:

Last name, first name, patronymic	Address, telephone #
_____	_____
_____	_____
_____	_____
_____	_____

1. General data on the liquidator

At first, I would like to ask you a few general questions and then to ask you to present your documents confirming that you are a liquidator.

1.1 Your nationality (choose one option)?

1	Belarusian	3	Ukrainian
2	Russian	4	other, specify_____

1.2 Your marital status (choose one option)?

1	married (that includes living together)	3	widower
2	single	4	divorced

1.3 What kind of education did you have (choose one option)?

1	hasn't finished high school	3	certificate training
2	high school	4	college

1.4 Please, show me the document which confirms that you are a liquidator.

a. *If the document is presented, the following information needs to be put down:*

Type of the document	Code, # and the date of issue	Organization which issued the document
_____	/_/_/_/_/_/_/_/_/_/_/_/_/_/_ 19/_/_	_____

b. *If there is no document (lost, etc.), please, tell me (if the liquidator forgot, put down "doesn't remember"):*

the reason, why he doesn't have the document_____

type of the document_____

the organization which issued the document_____

1.5 How many times were you sent to the 30 kilometers zone (choose one option)?

1	once	3	three times
2	two times	4	more, specify_____

Parts 2-4 should be filled out separately for every participation of the liquidator in the work within the 30 kilometers zone. Having filled out parts 2-4 for the first participation, fill out these parts the same way on separate sheets of paper for all other participations in case the liquidator has gone to the zone a few times. If the liquidator doesn't remember the dates you are questioning him about, put 99 for the "year" option (if he doesn't remember the year), and also, put 99 for the "month" option (if he doesn't remember the month). If the liquidator doesn't remember the exact day, ask him whether it happened in the beginning of the month, in the middle or in the end, and put down "n"-if it's the beginning of the month (Russian word for "beginning" starts with a "n"), put "s" - if it's the middle (Russian word for "middle" starts with a "s"), and put "k" for the end of the month (Russian word for "end" starts with a "k").

2. Information about the first participation in the activities at the 30 kilometers zone.

Now I am going to ask you a few questions regarding the reasons of your participating in the activities at the 30 kilometers zone and I will ask you to show me your documents (if you have them) which could confirm the time you claim to have spent in the zone. If you were there a few times, try to remember all your participations and to describe work conditions in the zone, and also living conditions outside of the 30 kilometers zone.

2.1 Please tell me which organization sent you to the 30 kilometers zone (choose one option)?

1 ☐ Army
2 ☐ military committee
3 ☐ organization of the Ministry of atomic industry (including power stations)
4 ☐ Ministry of Internal Affairs/KGB (Committee of State Security)

2.2 Please tell me the full name of that organization during the time when you were sent to the 30 kilometers zone and its location:

name_____
oblast (district)_____
city/other_____
If changed, give the new name_____

2.3 Please tell me the date when you started to work there /_/_/ /_/_/ 19/_/_

2.4 Please tell me the date when your job was over /_/_/ /_/_/ 19/_/_/

2.5 Do you have any official documents which could confirm the time you stayed in the 30 kilometers zone (choose one option)?

1 ☐ yes
2 ☐ no

If yes, please show me the documents.

If there are documents, the following information needs to be put down

Type of the document	Time period during which the person stayed in the 30 km zone of Chernobyl PS
_____	from/_/_/ /_/_/ 19/_/_/ to /_/_/ /_/_/ 19/_/_/
_____	same as above
_____	same as above

2.6 Please tell me the name of the organization you were with during the time you worked at the 30 kilometers zone (only if you haven't done that already).

2.7 Could you show me the official documents regarding the dosage of radiation you received(choose one option)?

1 ☐ yes
2 ☐ no

If "no", please specify the reason why you don't have any documents regarding the above matter:

1 ☐ lost
2 ☐ left at home
3 ☐ other, specify_____

If "yes", please show the documents(*If the documents were shown or the liquidator didn't show them but remembers having them, then it is necessary to put down the following information*):

Type of the document, organization	Code, # and date of issue	Time period, dosage and unit of measurement	Is this a total dosage?
_____	/_/_/_/_/_/_/_/_/_/_/ _/_/ 19/_/	from /_/_/_/_/_/19/ to/_/_/_/19/_/_/	1 yes 2 no 3 I don't know

2.8 Did you work shifts (choose one option)?

1 ☐ yes
2 ☐ no
3 ☐ yes and no, specify the dates of working shifts from /_/_/ /_/_/19/_ to /_/_/ /_/_/19/_/_/
9 ☐ I don't know

2.9 Please, tell me where did you usually work in the 30 kilometers zone and specify how much time (in percents) you worked in these conditions (choose all the options that apply)

1 ☐ outside the houses and transportation vehicles (in open air)
  1 ☐ if yes, specify how much time_____%
  2 ☐ no
  9 ☐ I don't remember
2 ☐ inside a house
  1 ☐ if yes, specify how much time_____%
  2 ☐ no
  9 ☐ I don't remember
3 ☐ in a transportation vehicle (for example, in automobile)
  1 ☐ if yes, specify how much time_____%
  2 ☐ no
  9 ☐ I don't remember
4 ☐ other, specify_____
  1 ☐ if yes, specify how much time_____%
  2 ☐ no
  9 ☐ I don't remember where I worked

2.10 Using the list of the localities, please name main areas where you worked and also the following information (*the interviewer should put down all the main areas-towns, villages-one by one, one per line*).

Area, region	Start date of work d/m/y	Duration (in days)	Average number of hours per day
a_____	/_/_/ /_/_/ 19/_/_/	/_/_/_/	/_/_/
b_____	same as above		

2.11 Using the list of the localities, please name main areas where you lived or the closest localities to the place you lived, and also, the following information (*put down all the localities, one per line*)

Area, region	Start date of staying there, duration in 24hr periods and average number of hours per day	Which building did you stay in mostly?
a._____	/_/_/ /_/_/ 19/_/_/ /_/_/ /_/_/_/ 24hr periods /_/_/ hours per day	1 in a tent 2 in a wooden house 3 brick or concrete house 4 other, specify 9 I don't remember
b._____	same as above	same as above

2.12 Please, tell me the reasons for your leaving the zone (choose one option).

1 ☐ your radiation dose has exceeded the permissible one
2 ☐ your radiation dose reached the permissible level
3 ☐ your business trip was over
4 ☐ you got sick
5 ☐ other, specify_____
6 ☐ I never left, I am still working there
9 ☐ I don't remember

3. The work conditions in the 30 km zone during the first participation in the activities

The following questions will be related to the methods of dosimetry, means of protection from radiation (if they were at all used) and the type of the work that you were doing when you were in the 30 km zone.

3.1 Was the amount of the radiation dose you received ever estimated (choose one option)?

1 ☐ yes
2 ☐ no
9 ☐ I don't know

If yes, please specify what was the method of estimation of your radiation dose, what was the approximate period of time during which your dose was estimated (*choose "no", "yes" or "I don't know" for each method; if "yes", put down the needed information*). In case your dose was estimated with a personal dosimeter, specify the number of a dosimeter which was used for each period (look at the photo in the booklet).

Method of estimation	Time period	Dosimeter #
With help of personal dosimeter (look at the photo in the booklet)	1 ☐ yes from /_/_/_/_/19/_/_/ to /_/_/_/_/19/_/_/ from.....to 2 ☐ no 9 ☐ I don't remember	/_/_/ /_/_/
By method of group dosimetry	1 ☐ yes from /_/_/_/_/19/_/_/ to /_/_/_/_/19/_/_/ from.....to 2 ☐ no 9 ☐ I don't remember	
According to the route documents	1 ☐ yes from/_/_/_/_/19/_/_/ to /_/_/_/_/19/_/_/ 2 ☐ no 9 ☐ I don't remember	

3.2 In case you had a personal dosimeter, how often did you use it (choose one option)?

1 ☐ all the time
2 ☐ only during the time of work
3 ☐ sometimes during work
9 ☐ I don't remember

3.3 Have you been returning the dosimeter to the dosimetry service on a regular basis (choose one option)?

1 ☐ yes
2 ☐ no
9 ☐ I don't remember

If "yes", please tell me how often did you do it (choose one option)?

1 ☐ every day
2 ☐ once a week
3 ☐ once in two weeks
4 ☐ once a month
5 ☐ as often as it was requested by the dosimetry service
9 ☐ I don't remember

3.4 Have you evaluated yourself the radiation dose you got during your work (choose one option)?

1 ☐ yes
2 ☐ no
9 ☐ I don't remember

If "yes", what was the result of your calculations regarding your dose? /_/_/_/_

Put down unit of measurement (choose one option)?

1 ☐ Bar
2 ☐ Rad
3 ☐ Roentgen
4 ☐ other, specify_____
9 ☐ unknown

Your reaction towards the effect of radiation during the time you spent in the 30km zone of Chernobyl power station: did you get more radiation than the others, why do you think so?

_____

_____

_____

3.5 Did you do the following types of work (choose one option in every line)?

Type of work	Yes	No	I don't remember
Participation in building of "Sarcophagus" directly at Chernobyl power station industrial platform	1 ☐	2 ☐	9 ☐
Removing of highly activated fragments and/or graphite pieces from the roofs of the buildings and platforms near ventilation pipes	1 ☐	2 ☐	9 ☐
Deactivation of the premises and equipment at Chernobyl PS	1 ☐	2 ☐	9 ☐

Type of work	Yes	No	I don't remember
Deactivation of industrial platform and the adjacent area, including equipment outside of the Chernobyl power station	1 ☐	2 ☐	9 ☐
Radiation investigation	1 ☐	2 ☐	9 ☐
Deactivation of auto transportation means, etc.	1 ☐	2 ☐	9 ☐
Repairing and servicing Chernobyl PS equipment	1 ☐	2 ☐	9 ☐
Other types of work inside Chernobyl PS area, specify	1 ☐	2 ☐	9 ☐
Deactivation work and burying of radioactive waste outside Chernobyl PS	1 ☐	2 ☐	9 ☐
Building of roads in the 30 km zone	1 ☐	2 ☐	9 ☐
Working as a driver	1 ☐	2 ☐	9 ☐
Being a security guard at Chernobyl PS or in the 30 km zone	1 ☐	2 ☐	9 ☐
Other types of work outside Chernobyl PS area	1 ☐	2 ☐	9 ☐

3.6 Have you ever used the following means of protection during the time of work in the 30 km zone (choose one option in each line)?

Means of protection	Yes	No	I don't remember
Respirator or gas-mask	1 ☐	2 ☐	9 ☐
Gloves	1 ☐	2 ☐	9 ☐
Protective glasses	1 ☐	2 ☐	9 ☐
Protective clothes	1 ☐	2 ☐	9 ☐
Lead apron	1 ☐	2 ☐	9 ☐
Special protective auto transportation means (armored automobiles, lead sheets in helicopters)	1 ☐	2 ☐	9 ☐
Other, specify_	1 ☐	2 ☐	9 ☐

3.7 Did you work at the Chernobyl power station industrial platform (choose one option)?

1 ☐ yes
2 ☐ no
9 ☐ I don't remember

3.8 Were you given iodine during your working in 30 km zone (choose one option)?

1 ☐ yes
2 ☐ no
9 ☐ I don't remember

If "yes", please put down the time period and the dosage
from /_/_/_/_/_/19/_/_/ to /_/_/_/_/_/19/_/_/
and the quantity of tablets per day /_/_/

3.9 Please, name the people who worked with you.

Last name, first name, patronymic	Position

4. The description of the first episode of work in the 30 km zone of Chernobyl PS during the first time when the liquidator being questioned participated in the activities in the zone

In this part I would like to ask you to remember your everyday work in detail. If you had to work in the 30 km zone during the first days after the incident, in other words, in the end of April or in May, then try to remember the episodes, during which you could have received a substantial dose of radiation.

4.1 Tell me, please, where were you working (use photos and maps/diagrams from the booklet - part B - and also, the decoded marks - pages 16-19-, lists of premises - pages 20-23 - and localities - pages 24-57 - from part A. Choose all the options that apply):

1 ☐ at the Chernobyl PS, inside the premises (fill out section a.)
2 ☐ at the Chernobyl PS, on the rooftops of the buildings (fill out section b.)
3 ☐ outside, at the Chernobyl PS, in the places other than above (fill out section c.)
4 ☐ outside the Chernobyl PS site(fill out section c.)
5 ☐ in means of transportation - work around all the 30 km zone, including the PS site - (fill out section d.)
9 ☐ I don't remember (move to question 4.2)

a. <u>On the Chernobyl PS site inside the premises</u> (if not, move to lines b. and c.):

a.1 Put down the premises where you worked (use schemes and photos from the booklet - part B - and also, decoded marks - pages 16-19 - and lists of premises - pages 20-23- from part A. Choose one number and put it down). /_/_/_/_/_/_/_/_/_/

a.2 How long did it take you to walk to your place of work after you entered the building (put down the time period in minutes)? /_/_/_/_/_/_/

a.3 Did you walked more than two stair flights?

1 ☐ yes
2 ☐ no

9 ☐ I don't know

a.4 What was the size of the premises you worked in(put down the size in square meters)? /_/_/_/_/_/_/_/_/_/_/

a.5 Were there any windows?

1 ☐ yes
2 ☐ no
9 ☐ I don't remember

a.6 If "yes", were they leaded?

1 ☐ yes
2 ☐ no
9 ☐ I don't know

a.7 What color were the walls (choose one option)?

1 ☐ white
2 ☐ gray
3 ☐ golden
4 ☐ silver
5 ☐ green
6 ☐ brown
7 ☐ other, specify_____
9 ☐ I don't remember

a.8 Were the doors massive (choose one option)?

1 ☐ yes
2 ☐ no
9 ☐ I don't remember

a.9 What was the floor covered with (choose one option)?

1 ☐ plastic
2 ☐ concrete
3 ☐ tiles
4 ☐ tree
5 ☐ other, specify_____
9 ☐ I don't remember

a.10 Was there any cumbersome equipment on the premises (choose one option)?

1 ☐ yes
2 ☐ no
9 ☐ I don't know

a.11 Describe some other details which would characterize your place of work on the premises

_____

_____

_____

b. <u>On the site of the Chernobyl PS on the rooftops of the buildings:</u>

b.1 Which rooftop (of which building) you were working at (use diagrams and photo from the booklet - part B - , choose one number from the map or diagram from pages 2-3 and put it down)? /_/_/_/_/_/_/_/_/

b.2 Were there any other buildings near by (choose one option)?

1 ☐ yes
2 ☐ no
9 ☐ I don't know

If "yes", put down buildings' numbers from the map/scheme from the booklet: /_/

b.3 Was the rooftop (choose one option)

1 ☐ higher than other buildings?
2 ☐ lower?
9 ☐ I don't remember

b.4 Did it have different levels (choose one option)?

1 ☐ yes
2 ☐ no
9 ☐ I don't remember

b.5 What was the roof size? (put down the size in square meters) /_/_/_/_/_/_/_/

b.6 What was the roof covered with (choose one option)?

1 ☐ concrete
2 ☐ slate
3 ☐ wood
4 ☐ tar
5 ☐ other, specify_____

b.7 Was the roof damaged in any way near the work site (choose one option)?

1 ☐ yes
2 ☐ no
9 ☐ I don't remember

b.8 Were there any wreckage or waste near the work site (choose one option)?

1 ☐ yes
2 ☐ no
9 ☐ I don't remember

b.9 Where was the stairway to the roof (choose one option)?

1 ☐ outside the building
2 ☐ inside the building
9 ☐ I don't remember

b.10 Describe any other details which would characterize the roof work site:_____

_____

_____

c. In open air:

c.1 If you worked on the site of the Chernobyl PS but not on the rooftops of the buildings, put down the number of the closest building to your place of work (use maps and photos from the booklet and put down the number) /_/_/_/_/

c.2 If you worked outside the Chernobyl PS site, then put down the name of the locality (region, district, etc.) that you worked at, or the closest to your place of work (use maps and lists of localities):_____

c.3 Were the following landmarks near your place of work (you may choose a few options)?

1 ☐ buildings
2 ☐ power lines
3 ☐ other landmarks, specify_____
9 ☐ I don't remember

c.4 What kind of equipment was located near your place of work (you may choose a few options)?

1 ☐ bulldozers
2 ☐ dump trucks
3 ☐ excavators
4 ☐ cranes
5 ☐ other equipment, specify_
9 ☐ I don't remember

c.5 What did you have under your feet (choose one option)?

1 ☐ soil
2 ☐ crushed stone
3 ☐ concrete
4 ☐ asphalt
5 ☐ sand
6 ☐ other, specify_____
9 ☐ I don't remember

c.6 Was a "stopping up" of radioactive dust ever conducted at your place of work (choose one option)?

1 ☐ yes
2 ☐ no
9 ☐ I don't remember

c.7 Describe some other details which would characterize your work site:

_____

_____

d. In means of transportation (working around the whole 30 km zone, including the Chernobyl PS site):

d.1 Name the type of mode of transportation that you worked in (choose one option)

1 ☐ bulldozer
2 ☐ bus
3 ☐ dump truck
4 ☐ car
5 ☐ tractor
6 ☐ crane
7 ☐ other, specify___
9 ☐ I don't remember

d.2 Was that mode of transportation equipped with means of protection from radiation (choose one option)?

1 ☐ yes
2 ☐ no
9 ☐ I don't remember

If "yes", describe them:_____

d.3 Describe the routes you were taking: roads, localities, industrial objects (use maps and lists of localities):

_____
_____
_____

4.2 Type of activities in an episode:

a. Tell me, please, in detail about what kind of work did you do and what kind of instruments and devices you used?

_____
_____
_____

b. How did you work (choose one option)?

1 ☐ in group
2 ☐ alone
9 ☐ I don't remember

c. Did you work at the "burial sites" (choose one option)?

1 ☐ yes
2 ☐ no
9 ☐ I don't remember

4.3 How did you get to work in an episode:

a. What type of transportation did you usually use to get to your place of work and back (choose one option)?

1 ☐ armoured troop carrier
2 ☐ bus
3 ☐ tractor
4 ☐ helicopter
5 ☐ car
6 ☐ truck
7 ☐ other, specify___
9 ☐ I don't remember

b. Describe the route you took to your place of work and back (choose one option)":

where were you coming from_____

where were you heading_____

landmarks along your route_____

c. Did you transfer from one transportation to another (choose one option)?

1 ☐ yes
2 ☐ no
9 ☐ I don't know

If "yes", put down the points at which you transferred_____

d. How much time did it take you to get from the place you lived at to work and back (put down the time period in minutes)? /_/_/_/_/_/_/_/

e. Additionally, did you have to walk to work after you got off the transportation (choose one option)?

1 ☐ yes
2 ☐ no
9 ☐ I don't remember

If "yes", put down the time period in minutes /_/_/_/_/_/_/

f. Describe the route you took on the way back from work:

where were you coming from _____

where were you heading_____

landmarks along your route_____

4.4 Food and rest during the time of work in the episode

a. Where did you eat during the time of work (use maps and photos from the booklet - part B)?

1 ☐ outside of the premises (put down buildings' numbers from the maps or diagrams, or the name of the locality):_____

2 ☐ on the premises (put down the building numbers from the map or diagrams, or the name of the locality):_____

3 ☐ inside the transportation (specify the type):_____

9 ☐ I don't remember

b. How did you get to the place where you ate (choose one option)?

1 ☐ on foot
2 ☐ by transportation
9 ☐ I don't remember

If by transportation, put down how much time it took to get to the destination (put down the time period in minutes) /_/_/_/

and the route you took_____

c. How much time did you have for lunch (put down the time period in minutes)? /_/_/_/_/

d. Where did you rest during your breaks (use maps and photos from the booklet and choose one option)?
   1 ☐ outside the premises (put down building numbers from the map and diagram 2-3):_____
   2 ☐ inside the premises (put down building numbers from the map and diagram 2-3, or the name of the locality):_____
   3 ☐ inside the transportation (specify the type):_____
   9 ☐ I don't remember

e. How did you get to the place of rest (choose one option)?
   1 ☐ on foot
   2 ☐ by transportation
   9 ☐ I don't remember

If by transportation, specify how much time it took you to get to your destination (put down the time period in minutes)? /_/_/_/_/
and the route you took_____

f. How much time during the working day did you spent resting (put time amount in minutes)? /_/_/_/

4.5 Time spent working in the episode:
from/_/_/ / /_/_/19/_/_/ to /_/_/ / /_/_/19/_/_/
Working days in the episode: (*mark by pen only those dates in the calendar which correspond to the working days of the liquidator in April-June of 1986 and the months starting from July of 1986 to the end of 1987*)
(NB! Please note that, according to the Slavic calendar, the week starts with Monday, not Sunday)

April/May of 1986						
Monday	Tuesday	Wed.	Thurs.	Friday	Sat.	Sunday
21	22	23	24	25	26	27
28	29	30	1	2	3	4
5	6	7	8	9	10	11
12	13	14	15	16	17	18
19	20	21	22	23	24	25
26	27	28	29	30	31	

June of 1986						
Monday	Tuesday	Wed.	Thursday	Friday	Saturday	Sunday
						1
2	3	4	5	6	7	8
9	10	11	12	13	14	15
16	17	18	19	20	21	22
23	24	25	26	27	28	29
30						

1986	1987	
July	January	July
August	February	August
September	March	September
October	April	October
November	May	November
December	June	December
December	July	December

4.6 Number of the hours you worked per day (average) /_/_/_/_/

4.7 Dosimetry control in the episode:

a. Did you change before work (choose one option)?
   1 ☐ yes
   2 ☐ no
   9 ☐ I don't remember

b. Did you start working as soon as you would arrive (choose one option)?
   1 ☐ yes
   2 ☐ no
   9 ☐ I don't remember

If "no", put down the time period in minutes you would spend before work /_/_/_/_/

c. Did you have to pass a point of control ("KPP") to estimate the level of radioactive contamination (choose one option)?
   1 ☐ yes
   2 ☐ no
   9 ☐ I don't remember

d. Did you put your feet in containers with manganese solution (choose one option)?
   1 ☐ yes
   2 ☐ no
   9 ☐ I don't remember

e. Did the dosimetry specialist control the work process or was he around during your work (choose one option)?
   1 ☐ yes
   2 ☐ no
   9 ☐ I don't remember

f. Was the supervisor of the work process in contact with the dosimetry specialist (choose one option)?
   1 ☐ yes
   2 ☐ no
   9 ☐ I don't remember

g. Was the dosimetry specialist a military officer (choose one option)?

1 ☐ yes
2 ☐ no
9 ☐ I don't remember

4.8 Your comments regarding the episode;

a. Do you think that the work process you've described was well organized and "tightly" controlled by your supervisor, the dosimetry specialist, etc. (choose one option)?
   1 ☐ yes
   2 ☐ no
   9 ☐ I don't remember

b. What was the most memorable moment during the time of work?

_____
_____
_____

c. Please, comment on anything else connected with the work you did in the episode.

_____
_____

5. General information regarding professional activities

Now I am going to ask you a few questions regarding your profession and possible unhealthy work conditions which you experienced, if applicable.

5.1 In the present, what professional group do you belong to (choose one option)?

1 ☐ student
2 ☐ farmer
3 ☐ industrial worker
4 ☐ administrative worker
5 ☐ freelance work
6 ☐ unemployed
7 ☐ not-working invalid or retired
8 ☐ other, specify_____

5.2 What professional group did you belong to before participating in the "clean-up" activities at the Chernobyl PS (choose one option)?

1 ☐ student
2 ☐ farmer
3 ☐ industrial worker
4 ☐ administrative worker
5 ☐ freelance work
6 ☐ unemployed
7 ☐ not-working invalid or retired
8 ☐ other, specify_____

5.3 Have you ever performed any work connected with radiation except for the one you performed during the "clean-up" work at the Chernobyl PS (choose one option)?

1 ☐ yes
2 ☐ no
9 ☐ I don't remember

If "yes", please specify the district of your professional activities, dates of work, name and location of the organization which you worked at (choose "yes" or "no" for every sphere of professional activities, if "yes", specify the necessary information).

Sphere of professional activities	Work period, month/year	Organization (name, location)
Medicine	1☐yes from....to from....to from....to 2☐no	_____ _____ _____
Nuclear industry (including PS)	1☐yes from....to from....to from....to 2☐no	_____ _____ _____
Industrial radiography	1☐yes from....to from.....to from....to 2☐no	_____ _____ _____
Army service as opposed to the above-mentioned occupations	1☐yes from....to from....to from....to 2☐no	_____ _____ _____
Other, specify _____ _____	1☐yes from....to from...to from....to 2☐no	_____ _____ _____

5.4 Have you ever worked at any of these "unhealthy" industrial productions (*show the list of these productions to the liquidator you are interviewing*), including the time you served in the Army (choose one option)?

1 ☐ yes
2 ☐ no
9 ☐ I don't remember

If "yes", please specify the production, dates of work, name and location of the organization which you worked at.

Production	Work period, month/year and work title	Organization (name, location)
_____ _____	from .....to _____	_____ _____
_____	from.....to	_____

5.5 Have you ever worked with any of these "unhealthy" chemical substances (*show the list of these substances to the liquidator whom are interviewing; choose one option*)?

1 yes
2 no
9 I don't remember

If "yes", please specify the chemical substance, dates of work, name and location of the organization which you worked at.

Chemical substance	**Work period, month/year**	**Organization (name, location)**
_____	from.....to	_____
_____	from.....to	_____
_____	from.....to	_____

6. Medical history

Now, try to remember whether you have ever been diagnosed with illnesses which I am going to ask you about.

6.1 Have you ever had problems with your thyroid (choose one option)?

1 ☐ yes
2 ☐ no
9 ☐ I don't remember

If "yes", please, specify the following information:

Name of the disease	**Year it was diagnosed**	**Hospital, its address (district, region)**
Goitre	19/_/_/	_____
Changes in (lymphatic)knots	19/_/_/	_____
Hypoterios	19/_/_/	_____
Hyperterios	19/_/_/	_____
Thyroidit	19/_/_/	_____
Other, specify_____	19/_/_/	_____

6.2 Has a doctor ever told you that you have a tumor (benign or malignant) or leucos (choose one option)?

1 ☐ yes
2 ☐ no
9 ☐ I don't remember

If "yes", please specify (put down for every tumor separately: first localization, hospital, where you were diagnosed, year of the first diagnosis and choose answers corresponding to the treatments you received).

a. First tumor

Localization_____
Hospital_____
Year of the diagnosis 19/_/_/

Treatment:	Yes	No	I don't remember
Radiation therapy	1	2	9
Chemotherapy	1	2	9
Surgical operation	1	2	9
Other, specify___	1	2	9

b. Second tumor

Localization_____
Hospital_____
Year of the diagnosis 19/_/_/

Treatment:	Yes	No	I don't remember
Radiation therapy	1	2	9
Chemotherapy	1	2	9
Surgical therapy	1	2	9
Other, specify____	1	2	9

6.3 Have you ever been treated with radiation therapy for other illnesses, which were not listed in question 6.1 (choose one option)?

1 ☐ yes
2 ☐ no
9 ☐ I don't remember

If "yes", please specify:
illness_____
hospital where you were treated with radiation therapy_____
year of treatment with radiation therapy 19/_/_/

6.4 Have you ever gone through the following x-ray tests (choose "no", "yes" or "I don't remember" for every x-ray test; if "yes", specify the number of the tests you took)?

X-ray tests		**Number of tests**
X-ray of teeth	1 ☐ yes, specify how many times	/_/_/_/
	2 ☐ no	
	9 ☐ I don't know	

9. Alcohol consumption

9.1 Presently, how often do you drink alcohol (choose one option)?

1 ☐ never
2 ☐ once a month or less
3 ☐ 2-3 times a week
4 ☐ once a week
5 ☐ a few times a week
6 ☐ every day

If you drink alcoholic beverages, then please tell me whether you usually drink the following drinks and how much do you drink per day (average)?

Alcoholic beverage		**Quantity (in milliliters)**
Beer	1 ☐ yes, specify 2 ☐ no	/_/_/_/_/
Vodka, including home-distilled vodka	1 ☐ yes, specify 2 ☐ no	/_/_/_/_/
Wine	1 ☐ yes, specify 2 ☐ no	/_/_/_/_/
Other, specify_____	1 ☐ yes, specify 2 ☐ no	/_/_/_/_/

9.2 Did you change your habits regarding alcohol consumption after your work at the Chernobyl PS zone (choose one option)?

1 ☐ nothing changed
2 ☐ now I drink more
3 ☐ now I drink less
4 ☐ I started to drink more after Chernobyl
5 ☐ now I don't drink at all

10. Conclusion

10.1 Thank you for answering my questions. If you'd like to add anything, please put down anything you find necessary.

_____

_____

_____

_____

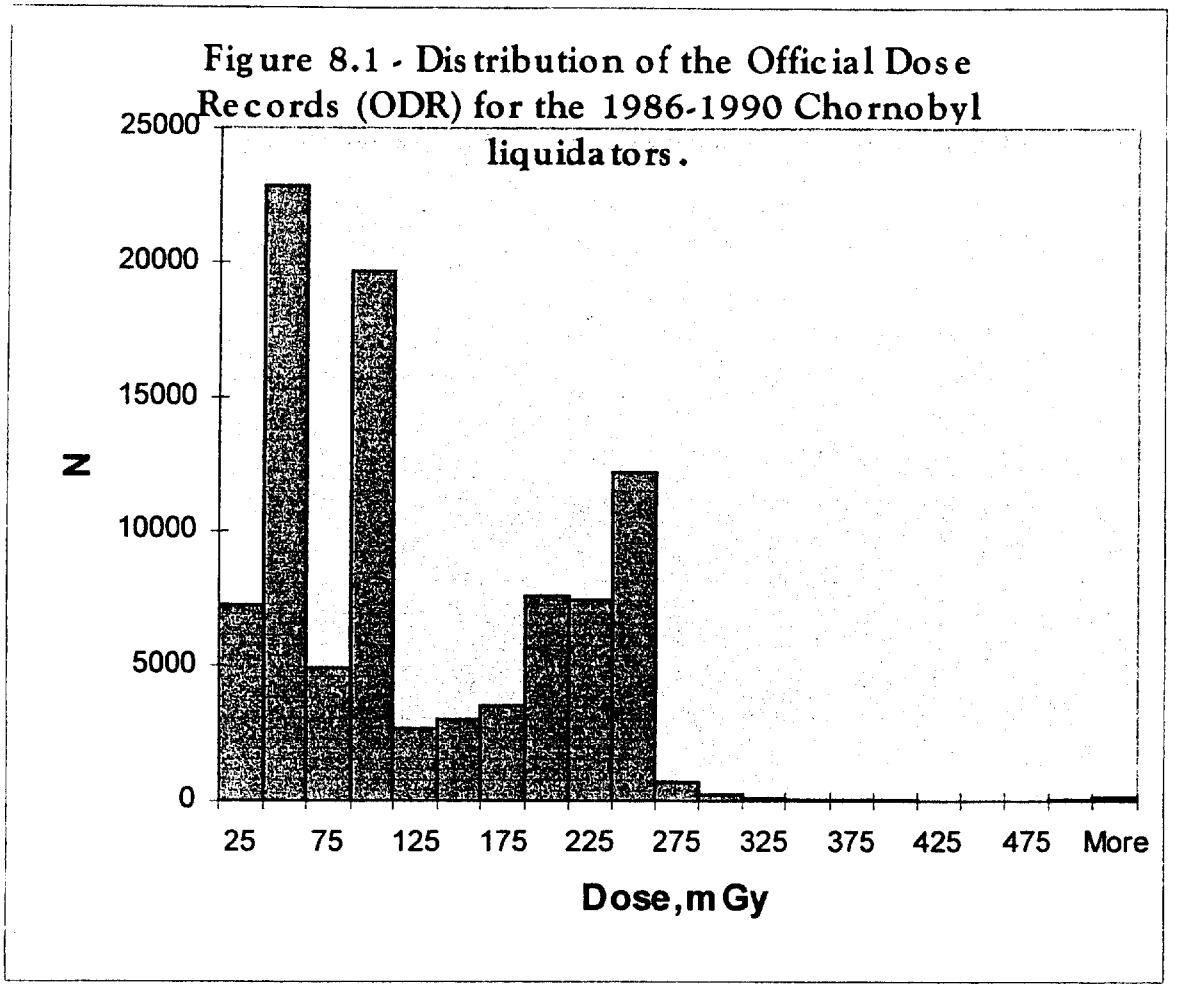
Time when the interview was finished:

_____ **hours/_/_/ minutes/_/_/**

APPENDIX 4

FIGURES

Appendix 4
Figure 8.1
(p. 31)



Appendix 4
Figure 14.1
(p. 44)

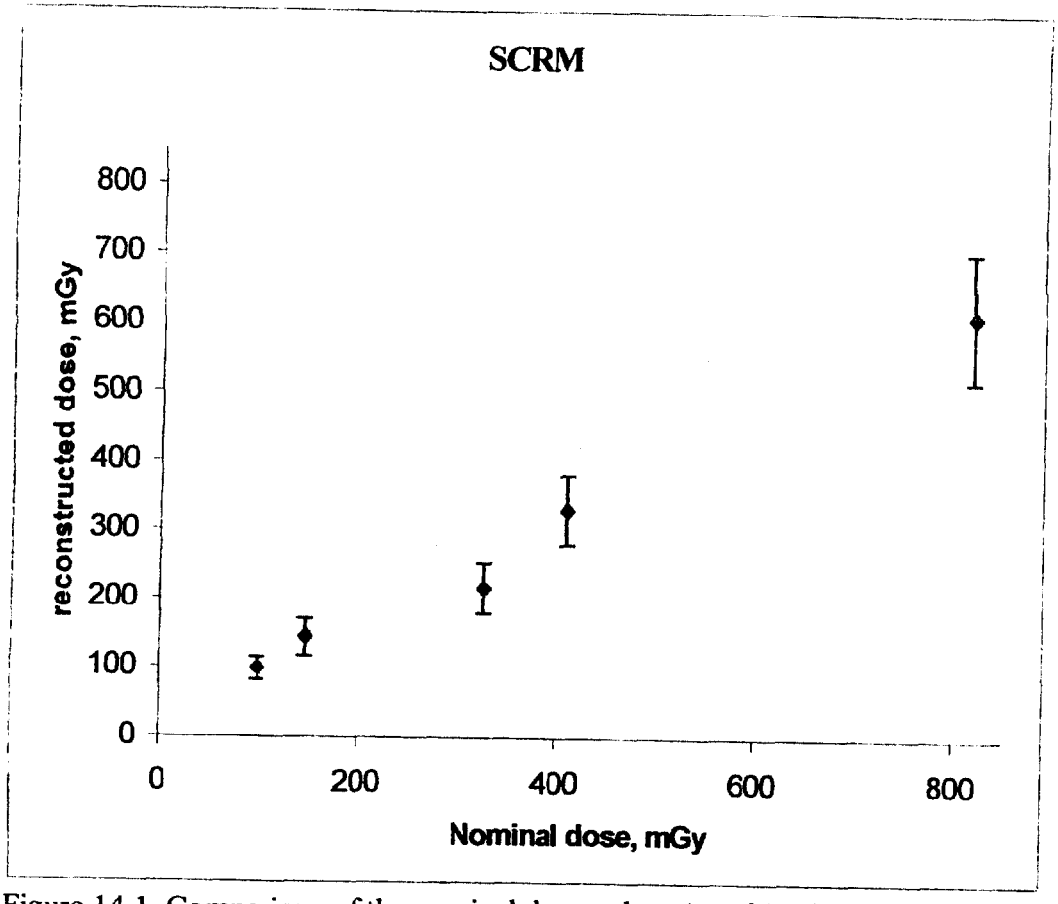


Figure 14.1. Comparison of the nominal dose values (x-axis) with those reconstructed by means of the EPR technique (y-axis).

Appendix 4
Figure 10.1
(p.33)

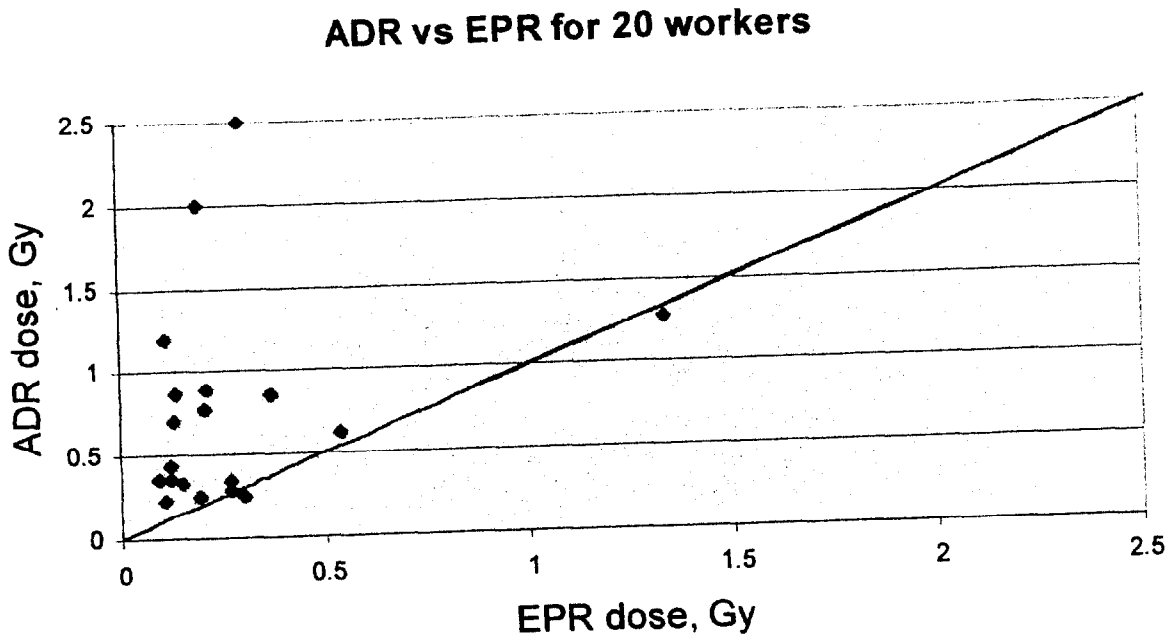


Fig 10.1. Comparison of ADR and EPR dose assessment for 20 ChNPP workers

Appendix 4
Figure 19.1
(p. 58)

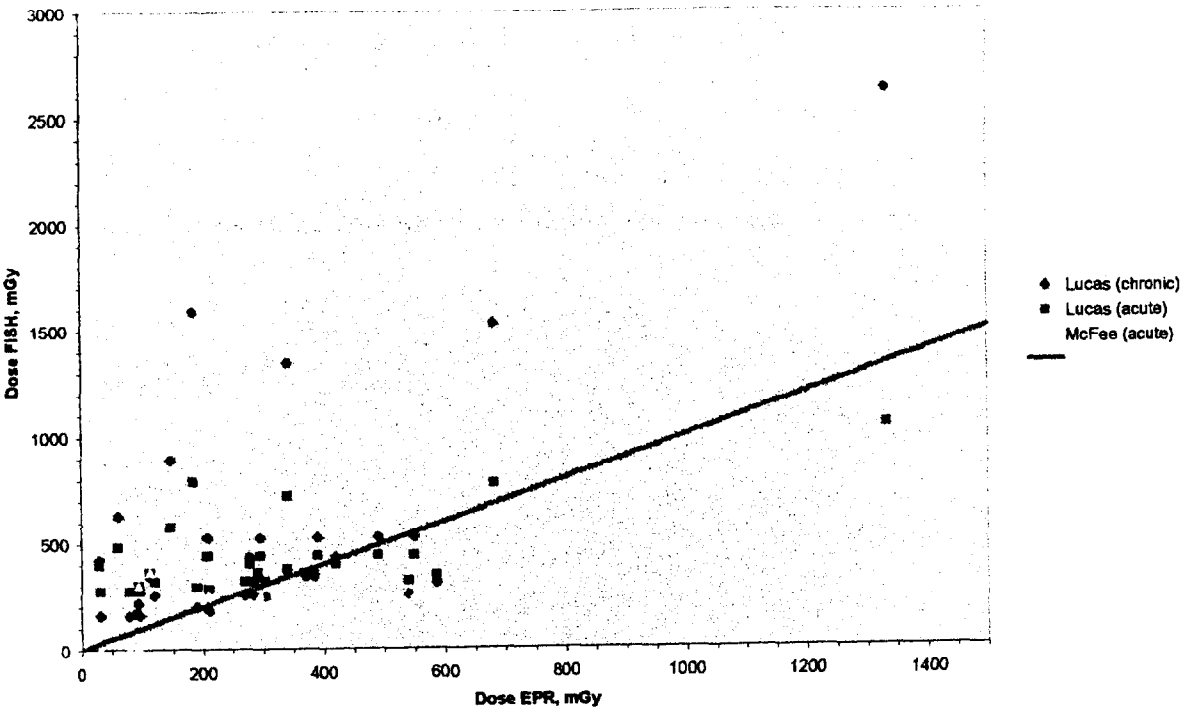


Fig. 19.1. Results of FISH vs. EPR doses.

FISH doses are determined using the same raw data (count of translocation) by applying different calibration formulae. The following calibrations were used:

1. Provided by Lucas [ref] for the case of chronic exposure.
2. Provided by Lucas [ref] for the case of acute exposure.
3. Provided by McFee [ref] for the case of acute exposure.

Appendix 4
Figure 19.2
(p. 59)

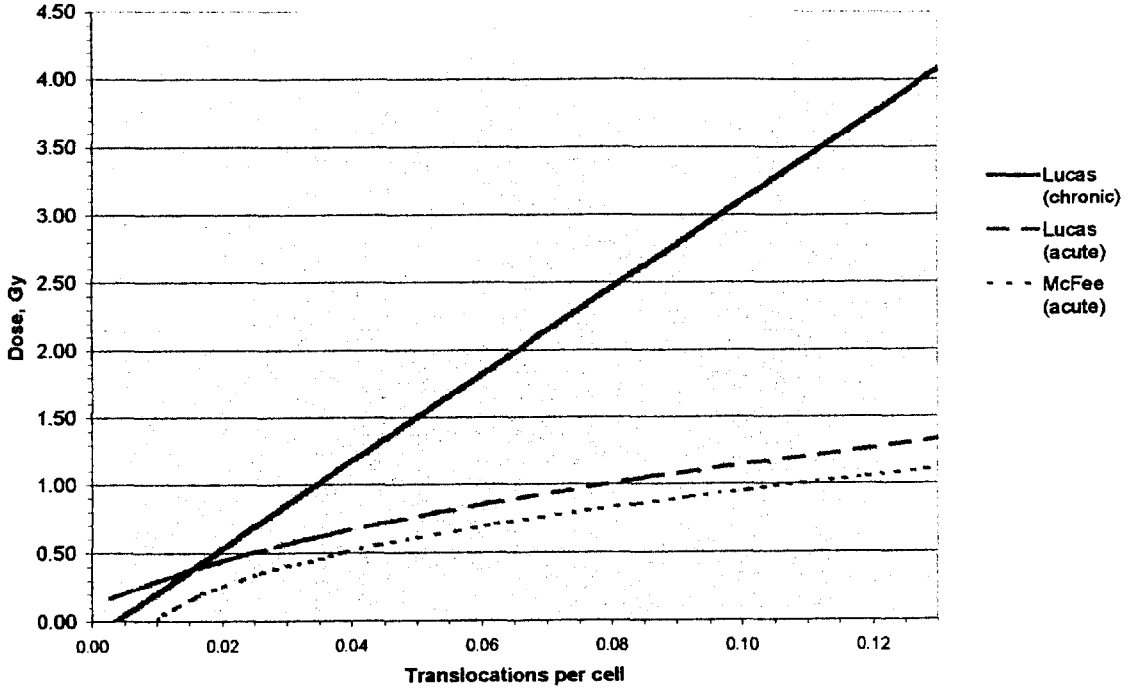


Fig.19.2. Three different *in vitro* calibration curves used for evaluation of doses by FISH.

Appendix 4
Figure 19.3
(p. 59)

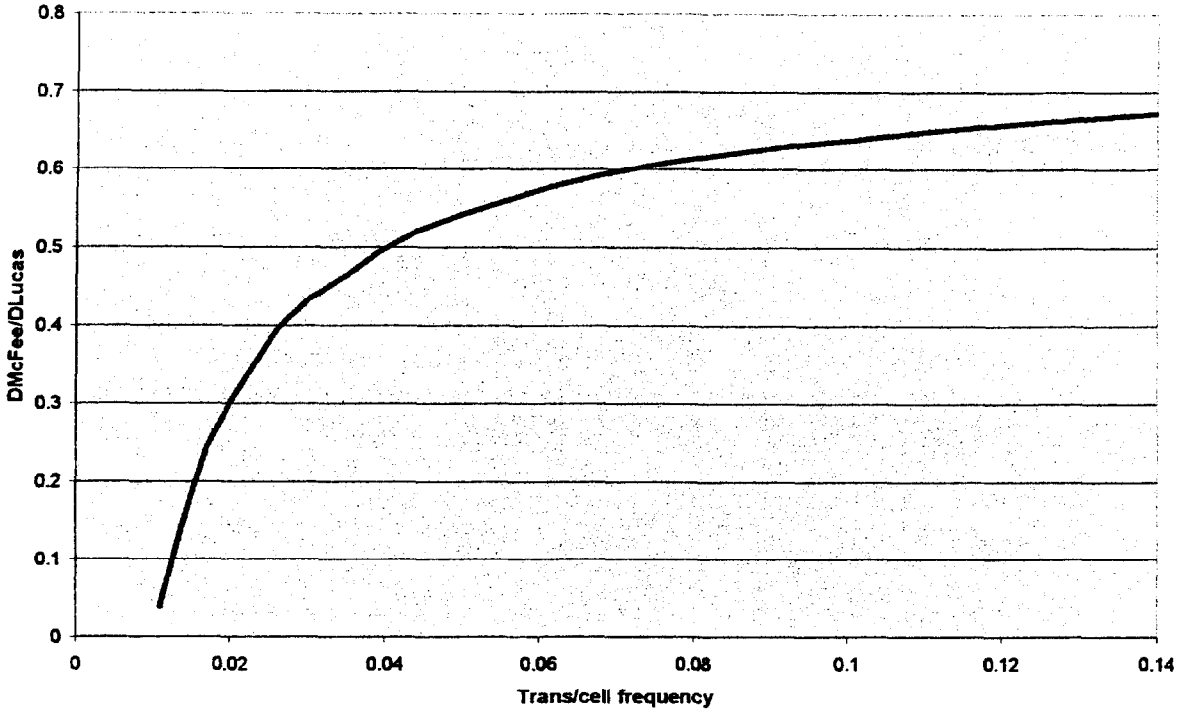


Fig.19.3. Ratio of calibration coefficients provided by McFee [ref] and Lucas [ref] for the case of acute exposure.

Appendix 4
Figure 19.4
(p. 60)

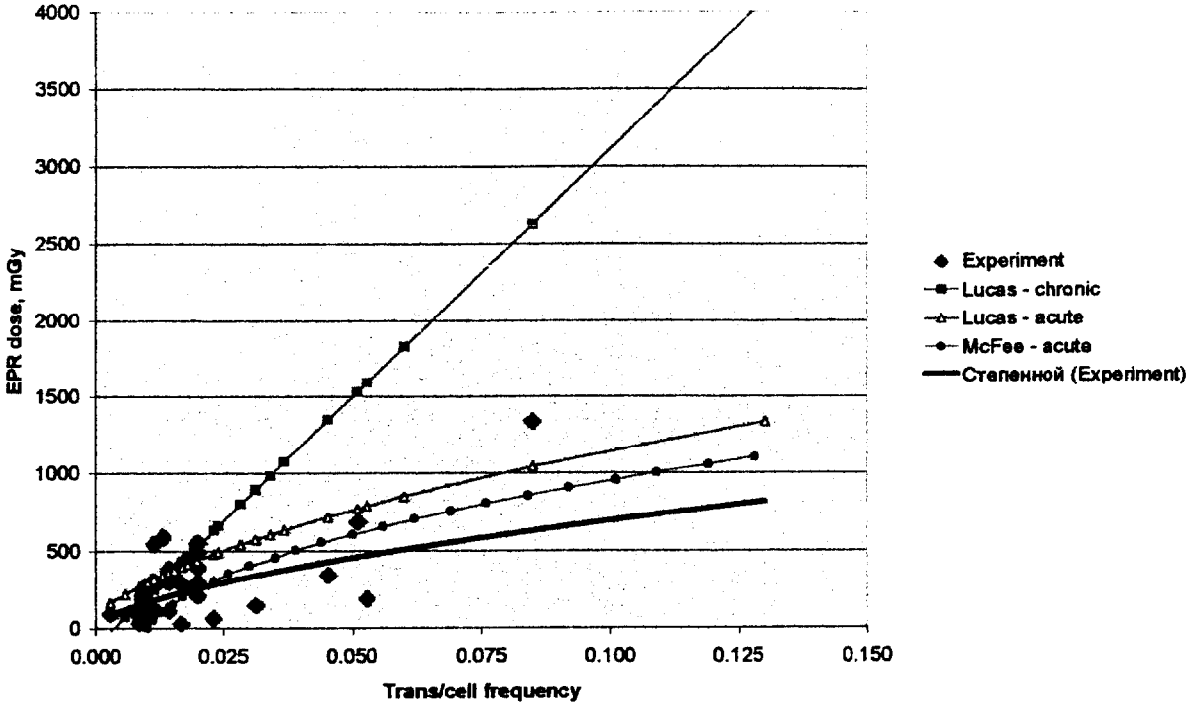


Fig. 19.4. Experimental data, *in vivo* calibration best fit (power law) and various *in vitro* calibration curves.

Appendix 4
Figure 19.5
(p. 60)

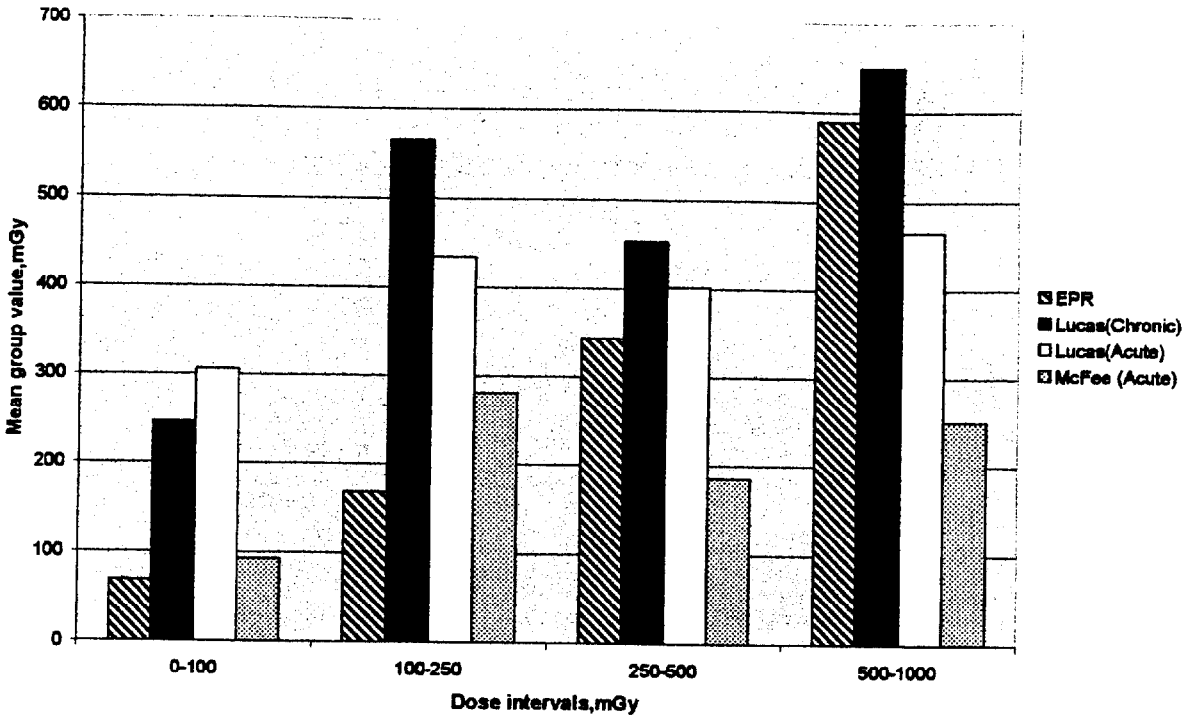


Fig.19.5 Group averaged dose estimates provided by various EPR and FISH (three calibrations)

Appendix 4
Figure 19.6
(p. 60)

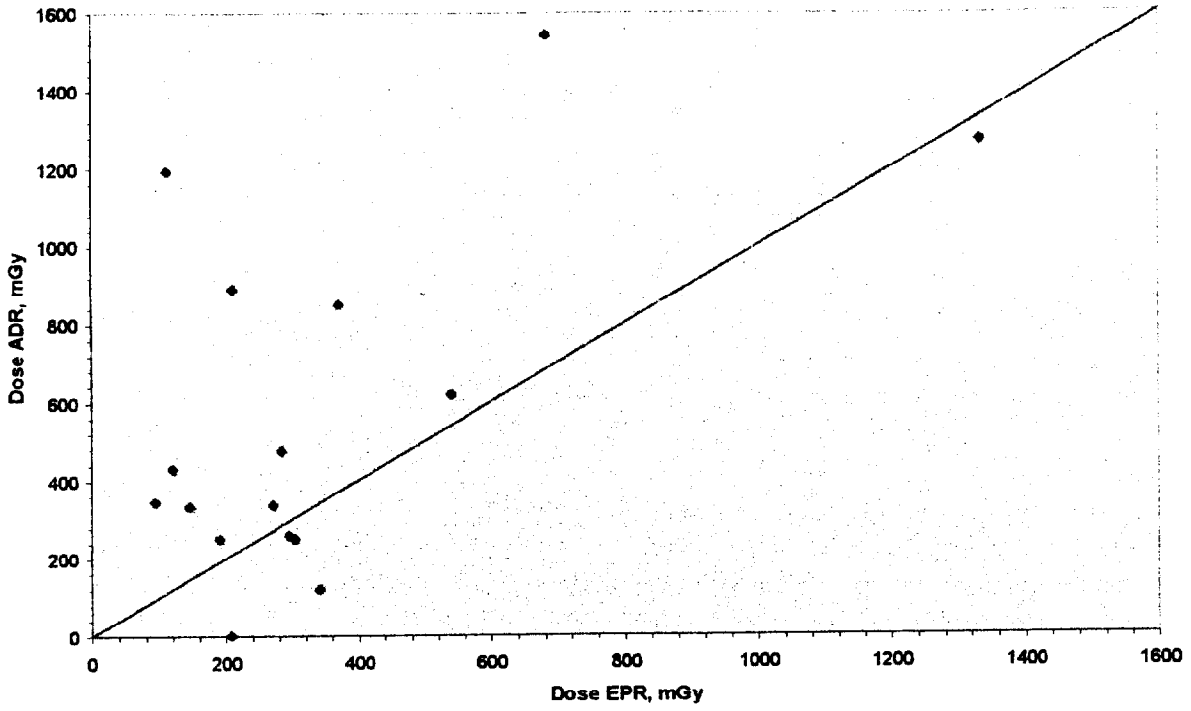


Fig.19.6. Comparison ADR vs. EPR for FISH exercise subjects

Appendix 4
Figure 19.7
(p. 60)

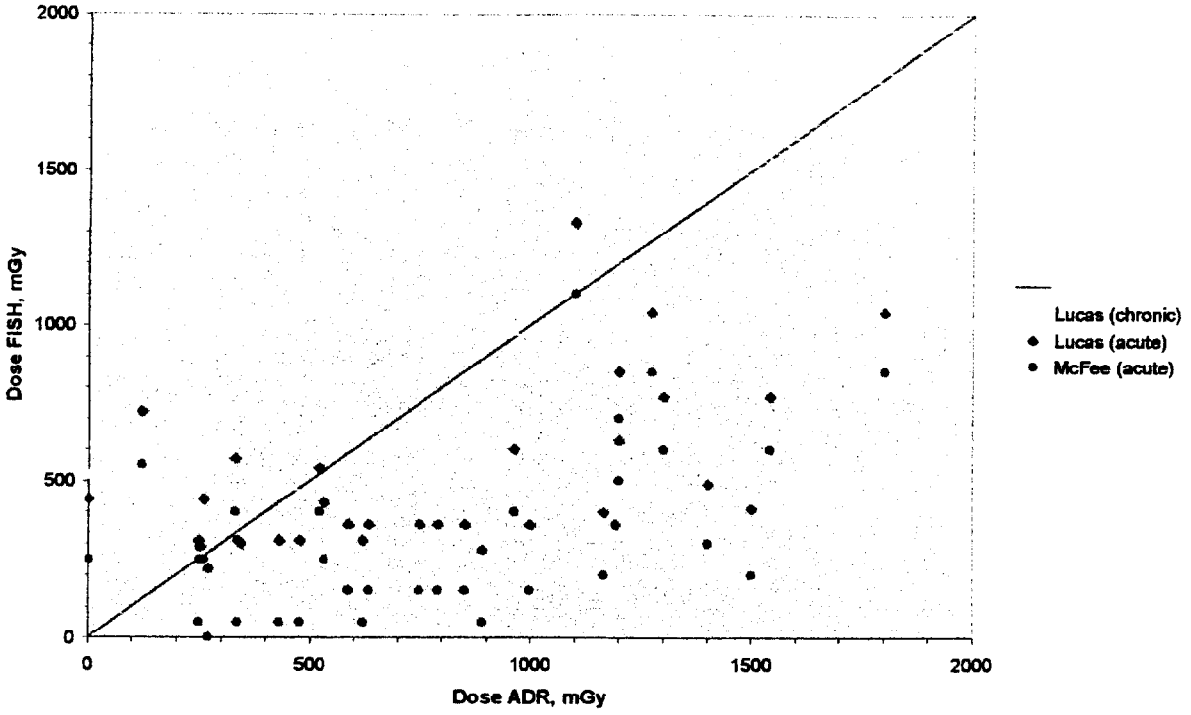


Fig.19.7. Comparison ADR vs.FISH for FISH exercise subjects

Appendix 4
Figure 19.8
(p. 60)

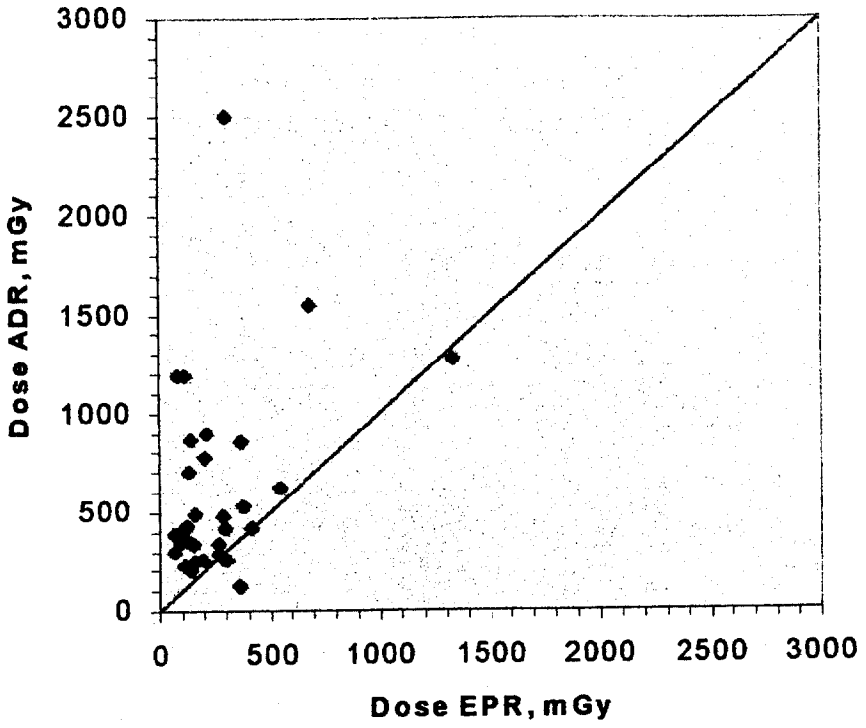


Fig. 19.8. Comparison ADR doses (results of analytical dose reconstruction) and EPR doses (results of EPR dosimetry). 32 subjects, mainly ChNPP staff.

Appendix 4
Figure 19.9
(p. 60)

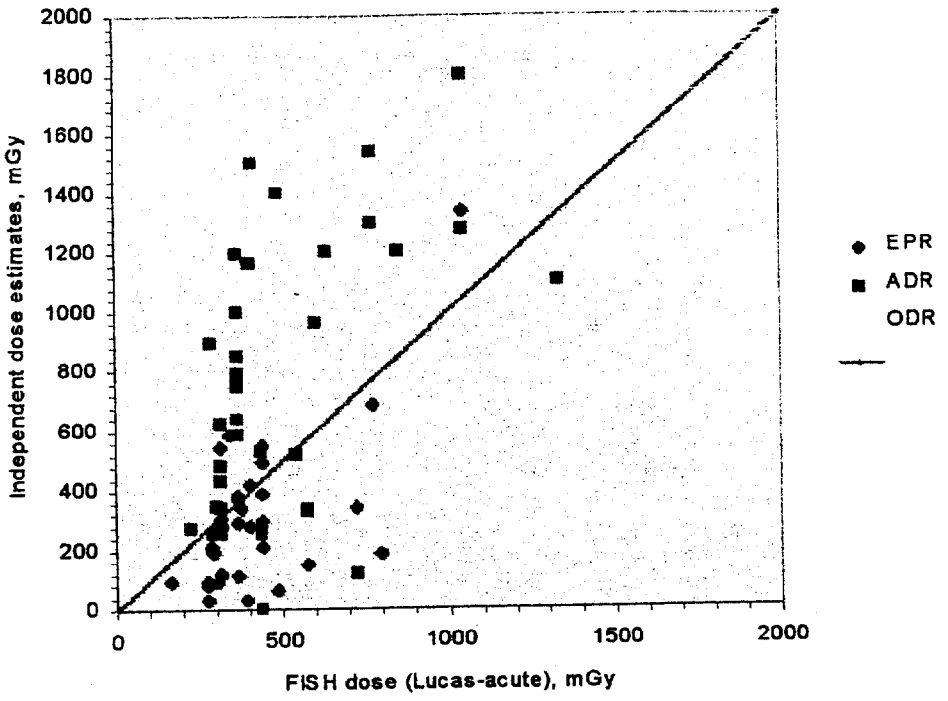


Fig. 19.9. Comparison of FISH doses with EPR/ADR/ODR dose assessments.
32 subjects - FISH vs. EPR
32 subjects - FISH vs. ADR
3 subjects - FISH vs. ODR

Appendix 4
Figure 19.10
(p. 60)

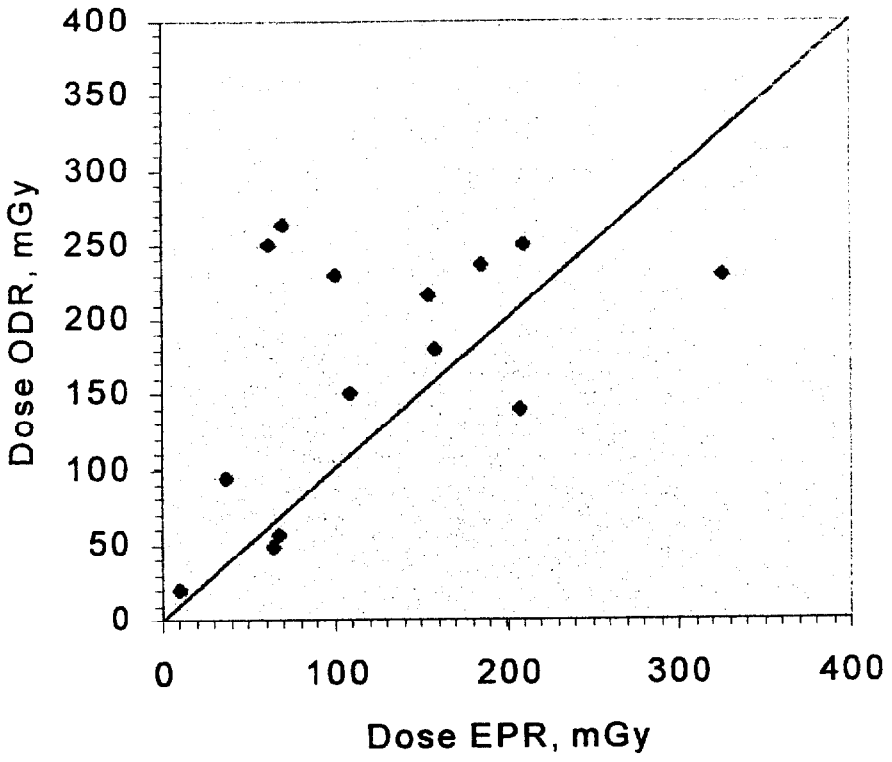


Fig. 19.10. Comparison ODR doses (official dose records) and EPR doses (results of EPR dosimetry). 14 subjects, mainly "partisans".

APPENDIX 5

POSTAL SUVEY QUESTIONNAIRE OF LIQUIDATORS TO OBTAIN INFORMATION ON TASKS AND AFFILIATION

Appendix 5

Mini questionnaire form developed for the postal survey of liquidators (Russian version and English translation).

ПОШТОВА ЛИСТІВКА

Куди Украина
252115, г. Киев
пр. Победы, 119

Кому **Поликлиника радиационного регистра**
ЛДВО

1. К какой организации Вы принадлежали во время работы по ЛПА?

☐ МО (кадровый состав) ☐ МВД ☐ ЧАЭС ☐ Прикомандированный к ЧАЭС ☐ ПО "Комбинат"
☐ МО ("партизан") ☐ УС-605 ☐ УС ЧАЭС ☐ Командированный в 30-км зону

Другая: _____?

2. Известна ли полученная Вами доза облучения?

Нет | Да

Каким образом определялась ее величина? Для ответа используйте следующие обозначения методов: 1 - при помощи персонального дозиметра, 2 - одним дозиметром на группу, 3 - по расчету дозиметриста, 4 - восстановлена по маршрутным листам, 5 - самостоятельная оценка, 6 - не знаю

I. методы: ☐☐☐☐☐☐,источник информации (орг-ция):_____,доза: ____
II. методы: ☐☐☐☐☐☐,источник информации (орг-ция):_____,доза: ____
III.методы: ☐☐☐☐☐☐,источник информации (орг-ция):_____,доза: ____

3. Какой вид работ Вы выполняли ?

☐ Строительство объекта "Укрытие" ("Саркофага")
☐ Очистка крыш от обломков реактора
☐ Ремонт и обслуживание оборудования ЧАЭС
☐ Дезактивация
☐ Строительство в 30-км зоне
☐ Охрана порядка
☐ Управление автотранспортом
☐ Обеспечение основных работ

Другая: _____?

4. Место работы ?	*обычно*	*в экстрем.случаях*		*обычно*	*в экстрем.случаях*
1) Крыша ЧАЭС	☐	☐	4) 10-км зона	☐	☐
2) Промплощадка ЧАЭС	☐	☐	5) 30-км зона	☐	☐
3) 5-км зона	☐	☐	6) иное	_____	_____

5. Как Вы считаете, была ли в Вашем случае фальсификация дозы облучения? ☐ Да ☐ Нет

English translation of the mini questionnaire form developed for the postal survey of liquidators.

POSTCARD

To: Ukraine
252115, Kyiv
Victory Boulevard, 119
To whom: Polyclinic of Radiation Registry
LDVO

1. For what organization did you work at Chernobyl?

Ministry of Defense (officer)
Ministry of Defense ("partisan")
Ministry of Internal Affairs
Chernobyl Nuclear Power Plant (ChNPP)
US-605
US ChNPP
Sent on mission to ChNPP
Sent on mission to the30-km zone
"Combinat"
Other_____

2. Do you know your irradiation dose?

If the answer is no, skip to question 3.
If the answer is yes:

How it was measured? For response use the following notation:
1 – by personal dosimeter;
2 – one dosimeter per group;
3 – estimation of a dosimetrist;
4 – with help of route list;
5 – personal estimation;
6 – don't know.

I. methods: "source of information (organization): _____" dose: _____
II. methods: "source of information (organization): _____" dose: _____
III. methods: "source of information (organization): _____" dose: _____

3. What kind of work did you do?

Construction of "Shelter" ("Sarcophagus")
Cleaning of reactor debris on the roof
Reparation and equipment maintenance at ChNPP
Decontamination
Construction in 30-km zone
Police activities

Vehicle driving
Support services
Other _____

4. Place of work

	Usually	In extreme cases
1) Roof of ChNPP		
2) Industrial zone		
3) 5 km zone		
4) 10 km zone		
5) 30 km zone		
6) Other		

5. Do you think that your dose was falsified? Yes No

APPENDIX 6

QUESTIONNAIRE DEVELOPED BY THE INTERNATIONAL DOSIMETRY GROUP

(TO BE REQUESTED FROM IARC)

APPENDIX 7

EPR INSTRUMENTATION: TECHNICAL INNOVATIONS MADE DURING PHASE I OF THE PROJECT

Appendix 7

EPR Instrumentation: Technical innovations made during Phase I of the Project.

The following components have been successfully installed on the SCRM's EPR spectrometer of BRUKER ECS 106 and were carefully tested:

- programmable goniometer under direct control of spectrometer's computer;
- high sensitive cylindrical microwave resonator;
- gaussmeter on the basis of NMR that allows to measure precisely the values of constant magnetic field during spectrum registration time;
- motherboard with a new processor and possibility of direct connection to computer SCRM's net, hard disk of 2.1 GB volume and 1.44" floppy disk drive. In fact, the computer of EPR spectrometer was entirely changed.

Additionally a number of laboratory facilities that are designed to simplify the procedure of sample treatment for EPR dosimetry purposes was delivered and is successfully used in routine dosimetry. Main components of this equipment are an ultrasonic bath (model BRANSON 3510, low speed saw (model ISOMET), two-column gydraulic press (model IMPERIAL PRESS) and many important small things. Some pictures of new facilities that was adapted for using in routine EPR dosimetry are shown in Figs. A3.1 – A3.3. Figure A3.1 represents using the goniometer together with cylindrical cavity. Goniometer consists of a few units that are labeled by a digit **1**. Unit **a** receives the signals from computer and passes them to the high precise motor **b**, which ensures the precision of 0.015 degree. Unit **d** is mounted directly to input hole of the cylindrical resonator **2** (the standard rectangular resonator may also be used with goniometer). Tube **3** with the sample inside is putting into resonator through precision unit of goniometer (only upper 10 mm side of the tube is seen in Fig. A3.1, all tube length is close to 200 mm). After being fixed by a special nut, goniometer can rotate the tube directly inside of the resonator. The goniometer is applied in routine EPR dosimetry for possible anisotropy averaging. This is doing in the following manner. Usually each sample is recorded at 10 different angles (6-12 accumulations per one angle) with an increment of 36 degrees and then all spectra corresponded to these angles are added together after g-factor normalization. The 3rd and 4th lines of a standard Mn^{2+}:MgO sample constantly placed into resonator are used for doing this.

Next essential improvement of EPR dosimetry routine technique is shown in Fig. A3.2. The low speed ISOMET saw, which is demonstrated there, gives possibility to cut fast and safely

each studied tooth into lingual and buccal halves. This, in its turn, gives an opportunity to determine possible x-ray dose.

Then both halves are treated in BRANSON ultrasonic bath (Figure A3.3) for long period of time. Previously each half is crushed into 1-2 mm pieces using two-column press; this results in significant reduction of time needed for enamel from dentine separation. It is necessary to emphasize, that few tens (up to 56) samples can simultaneously be treated using holder construction shown in Fig. A3.3.

One very important unforeseen improvement has been done after sudden breaking down of spectrometer's microwave bridge at the beginning of this year. Due to prompt reaction and financial support of project heads from US side, this component of spectrometer had been exported to Germany, where its qualified repair was made. The repaired bridge was returned to SCRM just before of BRUKER's service engineer visit. This gave possibility to carry out all required tests of upgraded facilities using in fact the new microwave bridge. As a result, EPR dosimetry had been stopped for minimum possible period of time and has been resumed on the new higher level.

The results of main tests that demonstrate the potential of new facilities are given below.

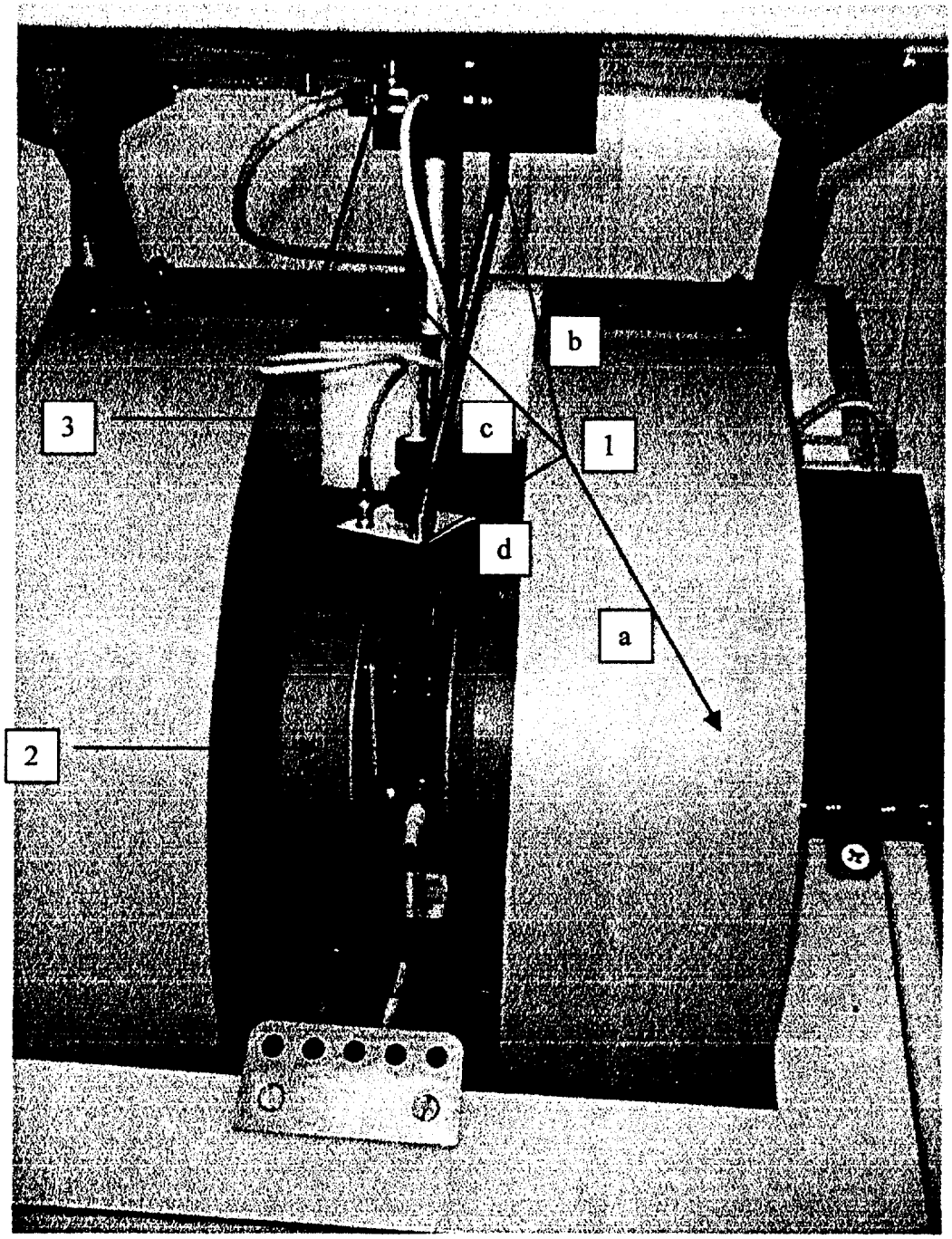


Fig. A3.1 Scheme of goniometer installation for using together with cylindrical resonator.
1 – goniometer model ER 218 PG1 including:
a – unit of goniometer control,
b – high precise motor,
c – mechanical gimbal drive,
d – precision unit.
2 – cylindrical microwave resonator model ER 4108,
3 – tube with sample inside of goniometer and resonator (only upper 10 mm part of tube is seen).

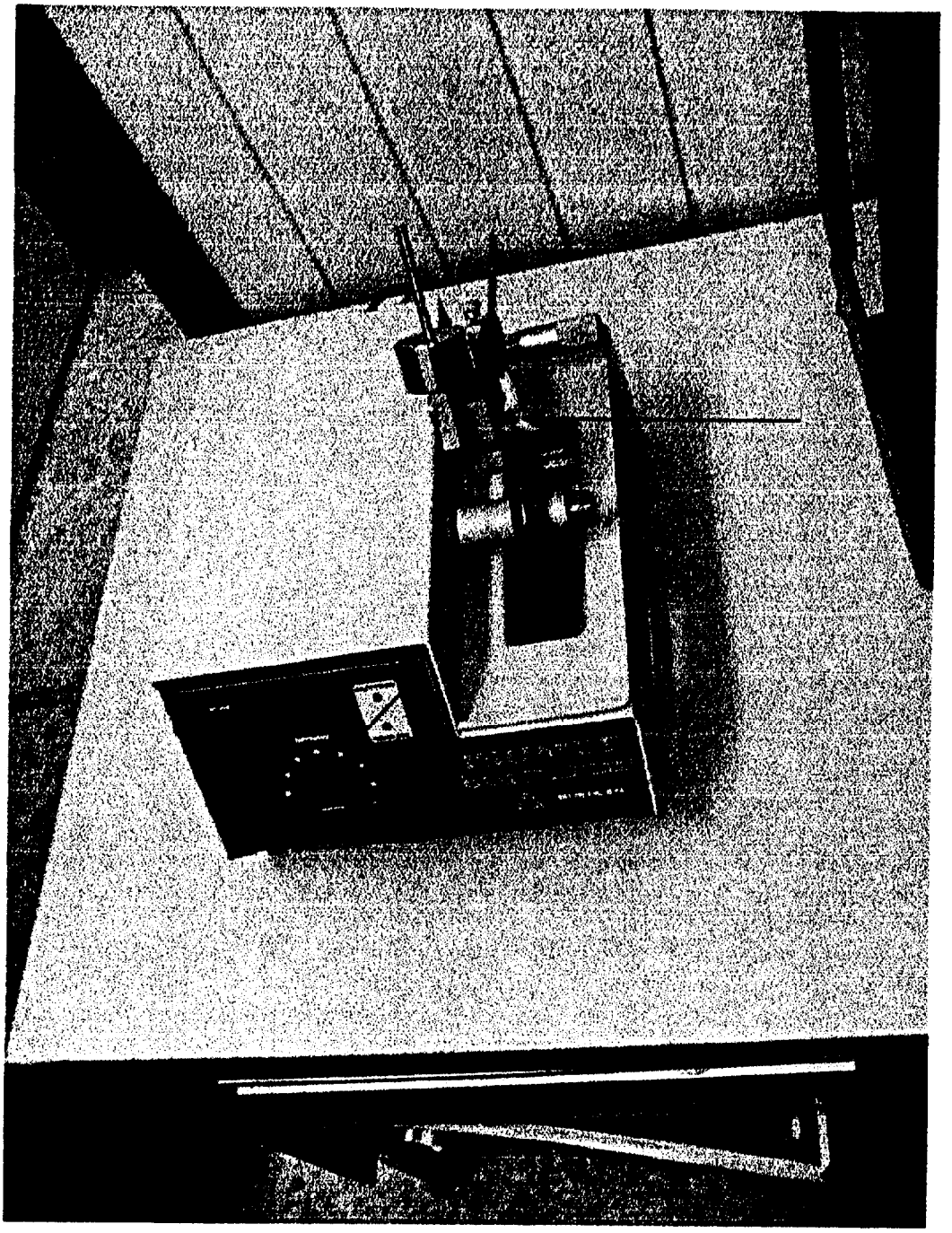


Figure A3.2 Using of low speed ISOMET saw for cutting of tooth samples in order to allow for contribution from possible x-ray diagnostic examinations. The arrow shows the tooth that should be cut.

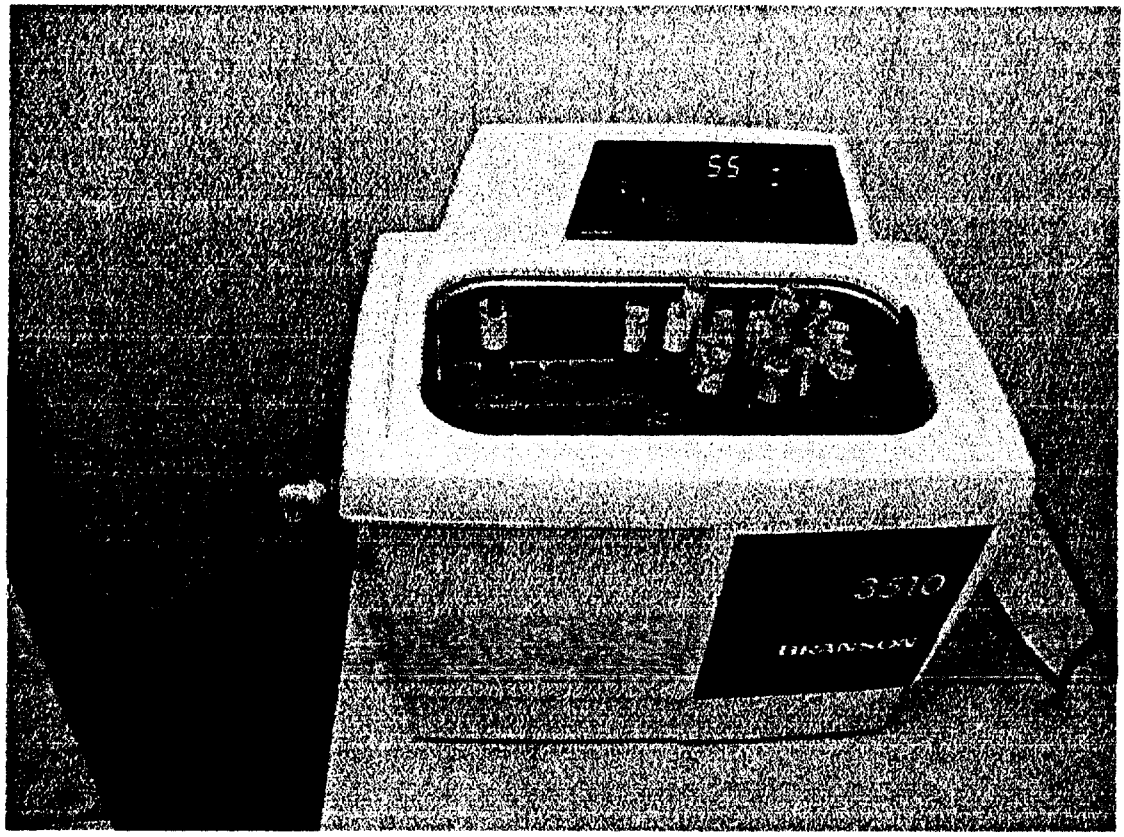


Figure A3.3 Application of BRANSON 3510 ultrasonic bath for extraction and purification of enamel by the method of chemical etching in alkaline solution. 16 tubes with samples that are simultaneously treated are seen in the present case. Maximum of working places is 56 for shown construction of tube holder.

Tests of upgraded facilities

1. Test of high sensitive cylindrical resonator.

Possible advantages of the high sensitive cylindrical TE_{120} resonator is due to fact that it have two times higher signal/noise ratio comparing to standard rectangular resonator, keeping up all advantages that latter resonator displayed in routine EPR dosimetry. The point is that the programmable goniometer as well as automatic tuning of spectrometer may be used with cylindrical resonator. Of course, a dielectric resonator possesses the highest sensitivity among the high frequency ones, but this resonator lacks both aforementioned feasibilities and therefore, it may not to be widely used in the routine EPR dosimetry.

The higher value of the signal/noise ratio concerns both time necessary for one dose reconstruction and its higher accuracy. The former is due to the fact that much smaller time (approximately by 1.5 times) is needed for cylindrical resonator in order to get the same value of the signal/noise ratio as for rectangular one. Respectively, the smaller the time interval the smaller contribution of the low frequency noises into intensity of the dosimetric signal of enamel, which explains latter effect.

Testing of the cylindrical resonator was carried out in two stages. Firstly, the "signal/noise" ratio was measured for both cylindrical and standard rectangular resonators. A standard "Weak Pitch" sample was used. The result of this test is shown in Fig. A3.4, the upper two spectra of which correspond to the sensitive cylindrical resonator, bottom two – rectangular one. Spectra 1 and 3 show the noise of corresponding resonators, while 2 and 4 ones – signals of the Weak Pitch sample. As can be seen in Fig. A3.4, the noise is practically the same for both resonators while intensities of the standard sample are different more than twice. Calculations via appropriate equations give the value 1220:1 in case of cylindrical resonator and 460:1 for rectangular one. Thus, cylindrical resonator use increases the "signal/noise" ratio by 2.6 times approximately.

For the second test, few enamel samples irradiated by two different doses - 100 and 1000 mGy - were prepared. The enamel was extracted according to the standard procedure used at the SCRM for the routine dosimetry of liquidators. After washing and crushing of samples to 250-850 μm fractions, 100 mg aliquots were weighted. They were irradiated using ^{137}Cs gamma-source with the error not exceeding $\pm 3\%$ controlled by the HARSHAW thermoluminescent dosimeters. After irradiation the samples were annealed at 95^0C for 2 hours.

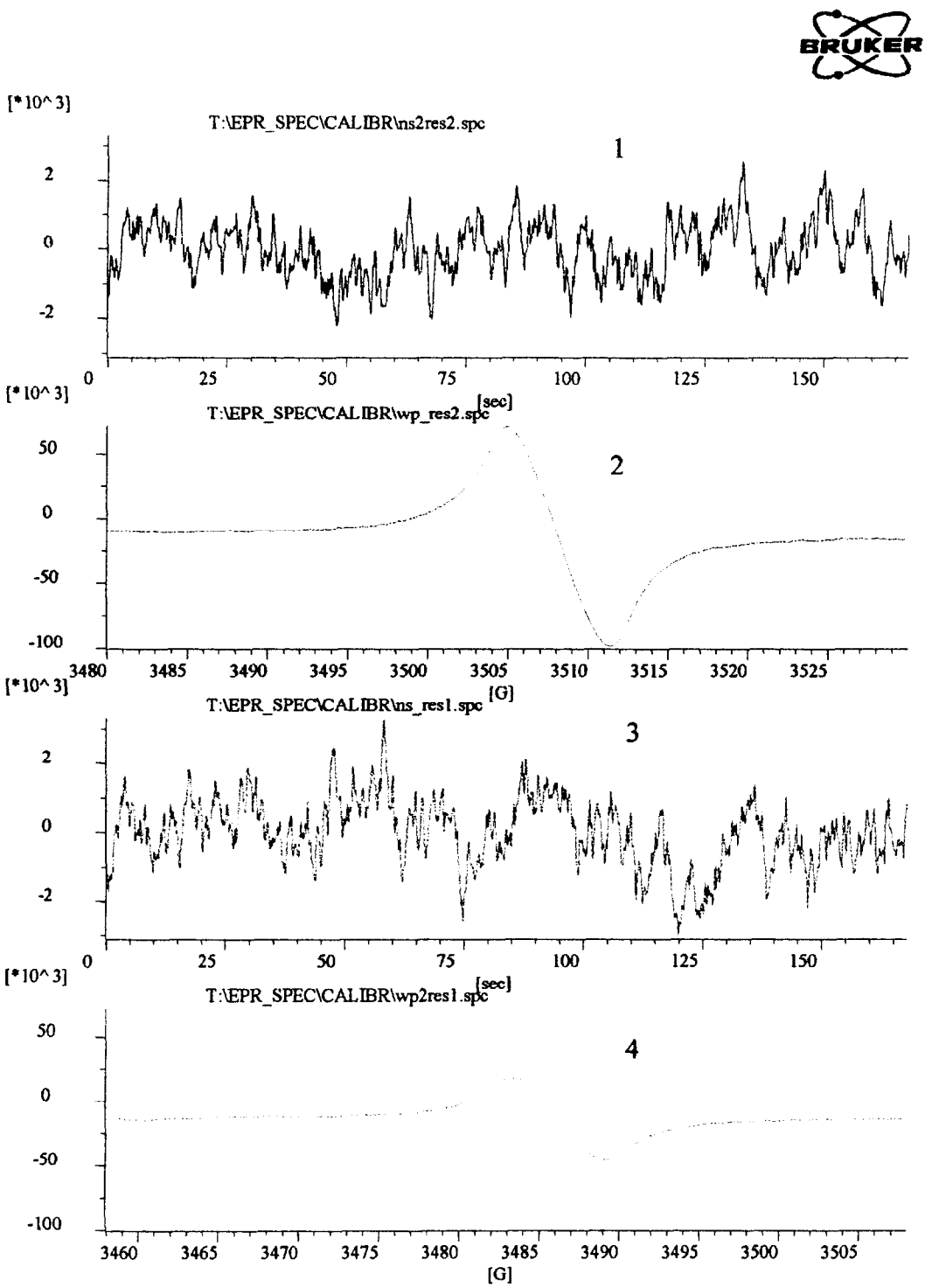


Figure A3.4 Spectra of noise (1 and 3) and a standard Weak Pitch sample (2 and 4) for the cylindrical (uper two ones) and rectangular (bottom two spectra) resonators.

EPR spectra were recorded using a modified EPR spectrometer with parameters typical for the routine dosimetry. Each sample was recorded three times using the goniometer as was described above. Such technique is advantageous as compared with continuous rotating of the tube because it allows avoiding line broadening due to the resonance frequency change which is the case especially for the more sensitive cylindrical resonator.

Thus, for each resonator 9 averaged (at 10 angles over 36 degrees) spectra of each sample were recorded. Besides rotating, the sample together with the tube was removed and repeatedly shaken up in the intervals between the averaged spectra recordings. As a result, we could compare the reproducibility of the enamel dosimetric signal recorded using standard rectangular and high sensitive cylindrical resonators. The procedure of evaluating the dosimetric signal intensity consisted of some conventional stages described in detail in the EPR Dosimetry Protocol section. Additional efforts were needed for the second stage of this procedure dealing with subtraction of a standard so-called native (g=2.0045) signal of enamel. The matter is that, as a rule, a conventional native enamel signal is obtained by averaging signals from a few tens of non-irradiated persons aged before 25. In present case, to compose this signal the spectra of few non-irradiated teeth were used (with no additional signals).

The data received for the samples under study are presented in Table A3.1. As it can be seen the use of the cylindrical resonator insignificantly effects accuracy of dosimetric signal measurements. The reproducibility of the 100 mGy signal measurement was higher by 7% for the rectangular resonator; for the doses of 1 Gy the higher reproducibility (by about 1%) was for the cylindrical resonator. In general, one may expect such result in case of the identical time of the spectrum recording for both resonators as it was in present case. Here the advantage of the cylindrical resonator is mainly in improving the signal/noise ratio. The time of the spectrum recording is directly connected with this ratio. As it is seen from Table A3.1, this ratio for the cylindrical resonator was by 2.1 times higher than for the rectangular one while recording signals of the enamel irradiated with the dose of 100 mGy, and was by 2.0 times higher for the samples with 1Gy. These values were calculated for the noise measured over 10 G in the middle of the interval between the dosimetric signal and the fourth line from the standard sample Mn^{2+}:MgO.

Advantages of the cylindrical resonator may also be illustrated in Fig.A3.5 where dosimetric signal (D.s.) of the same sample with the dose of 100 mGy is shown for the both resonators. Correction for the respective signals of the empty tube and a standard native signal was previously done for both spectra in this figure.

Table A3.1. Reproducibility of the dosimetric signal measurement and signal/noise ratio values in the samples with doses of 0.1 (No.1) and 1 (No.2) Gy recorded at rectangular and cylindrical resonators.

№ of a tooth/ its dose, mGy	Number of spectrum	Dosimetric signal intensity at rectangular resonator	Mean intensity (relative error)	Signal/noise ratio	Dosimetric signal intensity at cylindrical resonator	Mean intensity (relative error)	Signal/ noise ratio
1/ 100	1	17.6	20,0 (11.1)	0,91	27,4	33,8 (18,4)	1,89
	2	22		1,12	39,8		2,88
	3	20,3		1,25	34,3		2,17
2/ 1000	1	178.4	164,3 (4,0)	7,5	275,7	276,5 (3,2)	16,1
	2	162		8,1	267,9		15,4
	3	152.4		7,1	285,8		14,9

2. *Test of programmable goniometer.*

Goniometer use in EPR dosimetry of enamel is proved to improve the accuracy of the dose reconstruction procedure. The importance of such application is due to the fact that anisotropy effect in the retrospective dosimetry of enamel is rather significant even in case of the fine-grained samples. It results in higher errors during dose reconstruction which may be compensated by extra time needed for many times recording of the same sample and thoroughly shaking it during intervals between spectrum recording followed by averaging the resulted spectra (mathematical averaging). The other way of goniometer use is slow rotation of the sample with tube during spectrum recording thus leveling the anisotropy effect (physical averaging).

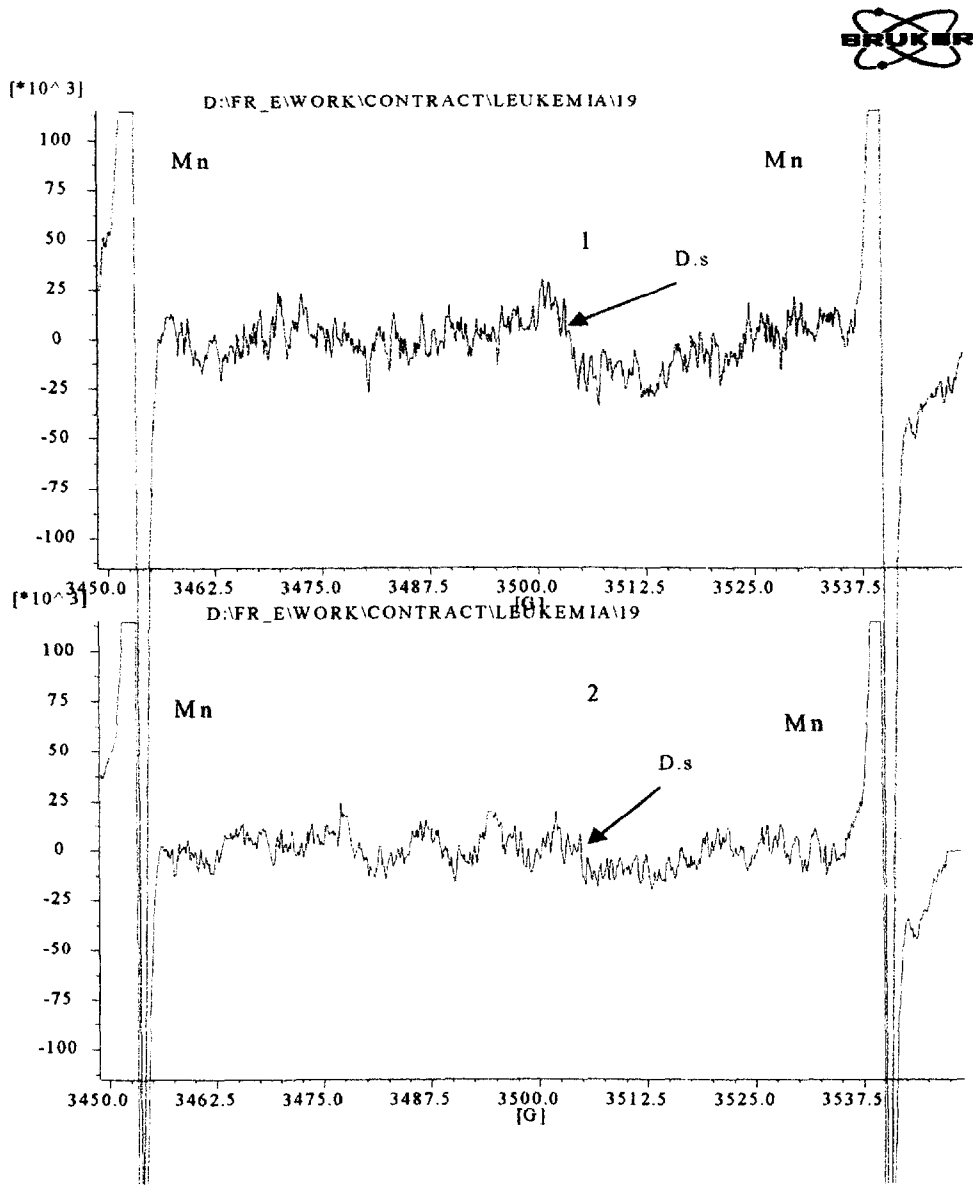


Fig. A3.5 Dosimetric signal (D.s.) in the enamel sample with the dose of 100 mGy recorded using the same parameters for both cylindrical high sensitive (curve 1) and rectangular (curve 2) resonators.

A ratio of the dosimetric signal intensity to the noises is approximately twice for the cylindrical resonator as compared with the rectangular one. In both cases 120 accumulations of the signal was made. It took about 45 min.

For the study, 6 enamel samples were prepared and irradiated by two different doses, namely 100 and 1000 mGy, three samples for each dose. The samples were prepared according to the standard procedure used at the SCRM for liquidators' routine dosimetry. Only non-irradiated teeth of students aged under 25 years were used for this experiment.

For investigations 100 mg aliquots were weighted. EPR-spectra were recorded using spectrometer ESR 300 Bruker with the parameters typical for the routine enamel dosimetry. Each sample was recorded 3 times in two regimes, i.e. using goniometer and without it. Thus, 6 spectra of each sample were recorded. While doing this, the sample with a tube was taken from the resonator and shaken repeatedly in the intervals between spectra recording. As a result, it was possible to compare reproducibility of the dosimetric signal of enamel while using goniometer and without it.

Procedure of dosimetric signal evaluation involved consisted of only standard stages.

The found results are presented in Table A3.2. This Table shows both the results of single spectrum evaluation and values averaged over three measurements. As can be seen from the Table A3.2, the accuracy of the dosimetric signal intensity is much higher in case of goniometer, being on the average of 8 % (by three times) better for the signals close to 100 mGy and 0.5 % - for the doses of 1 Gy. This result is additionally illustrated in Fig. A3.6 which shows mean values and possible error ranges (within one standard deviation) for the samples with 100 mGy dose obtained with goniometer and without it.

3. Test of high precision gaussmeter.

The main destination of gaussmeter use in the routine EPR dosimetry is high precision measurement of constant magnetic field during time of spectrum registration. This gives a possibility, at known values of resonance frequency, to calibrate the spectrum x-axe in the terms of g-factor values instead of magnetic field ones. The last fact would simplify the development of automatically working procedure of spectrum treatment aimed to determine dosimetric signal intensities as well as cumulative doses with more precision and objective. It is necessary to emphasize that 3rd and 4th lines of the standard Mn^{2+}:MgO sample is presently used when procedure of spectrum g-factor normalization is applied; and manipulation procedure itself requires high level skills and is applied manually using EPR spectrometer software. Respectively, the influence of the subjective factor when intensity of dosimetric signal is determined is essential.

Table A3.2. Reproducibility of dosimetric signals in the samples of enamel with the dose of *100 (№1-№3) and 1000 (№4-№6) mGy recorded using goniometer and without it.*

Tooth №	Spectrum №	Intensity without goniometer	Mean (relative error ,%)	Intensity with goniometer	Mean (relative error, %)
Dose 100 mGy					
1	1	15,9	14,1±1,9 (13,5)	13,7	13,9±0,4 (2,9)
	2	12,0		13,7	
	3	14,4		14,4	
2	1	18,3	18,4±2,2 (12,0)	18,1	18,0±0,8 (4,4)
	2	16,3		17,1	
	3	20,7		18,8	
3	1	15,0	16,7±2,1 (12,6)	16,4	16,4±0,4 (2,4)
	2	16,1		16,8	
	3	19,0		16,0	
Dose 1000 mGy					
4	1	129,9	128,2±2,5 (2,0)	128,2	128,4±2,2 (1,7)
	2	125,3		130,6	
	3	129,3		126,3	
5	1	162,5	160,6±2,3 (1,4)	160,8	159,0±1,8 (1,1)
	2	158,0		159,2	
	3	161,2		157,2	
6	1	157,0	154,3±4,1 (2,7)	150,9	153,7±2,8 (1,8)
	2	149,6		153,9	
	3	156,4		156,4	

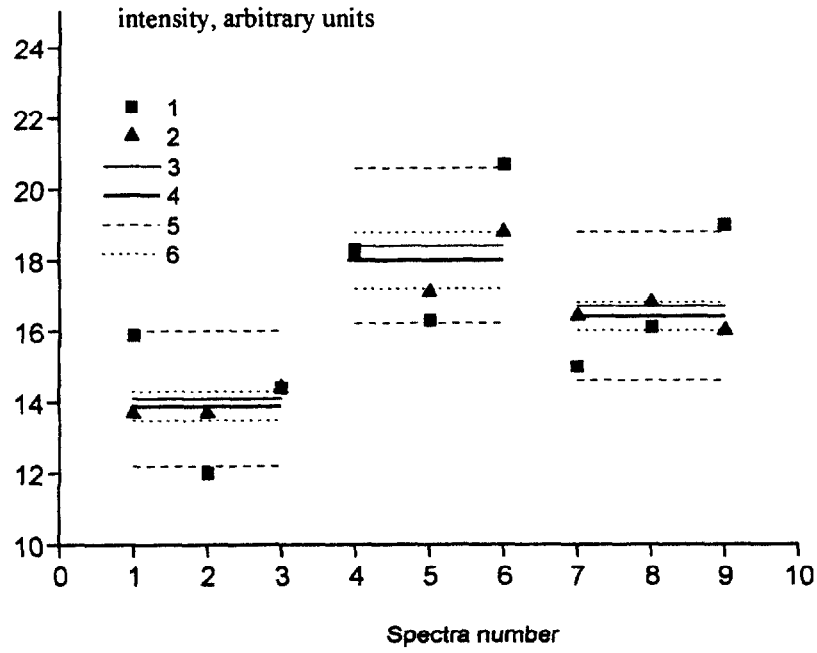


Fig A3.6 Reproducibility of the dosimetric signal in enamel samples with 100 mGy exposure dose in case of goniometer and without it. Spectra 1-3 correspond to the sample №1, 4-6 – to the sample №2, 7-9 – to the sample №3.

1 – intensity of the dosimetric signal received without goniometer,

2 – the same intensity using goniometer,

3, 4 – mean value of intensity (three spectra) without goniometer and with it, respectively,

5 – mean value "plus-minus" sigma without goniometer,

6 – the same as in 5 but using goniometer.

The results of gaussmeter testing are shown in Fig. A3.7, where few EPR spectra of the sample exposed by 0.5 Gy are given. Spectrum 1 was recorded without gaussmeter use (values of magnetic field were determined by Holl probe mounted into magnet) while spectrum 2 – with using high precision gaussmeter. Spectrum 3 is difference of previous two ones and shows clearly that the absolute error of magnetic field measurement using the Hall probe (old spectrometer configuration) can reach approximately two gauss which is equivalent to signals-artifacts of the same scale of magnitude as the initial dosimetric signal has. It is necessary to remind that absolute field values had not been measured in previous spectrometer configuration, and spectra were g-factor calibrated using 3rd and 4th lines of the standard Mn^{2+}:MgO sample, which made the procedure of dosimetric signal measurement more complicated.

Apart of precise measurement of magnetic field values, the gaussmeter use helps to reduce significantly time needed for one spectrum registration. This effect is due to essential reducing of field sweeping range from 100 G (former spectrometer configuration) to ca. 50 G (configuration with gaussmeter). Former value corresponded to a requirement to have 3rd and 4th lines of the Mn^{2+}:MgO standard on the each spectrum and therefore it is not necessary with gausmeter use. Latter value is more corresponding to the real parameters of enamel EPR signals in the x-band of microwave frequency.

It is necessary to emphasize that mentioned gaussmeter advantages may be realized only together with frequency meter, delivering of which should be done during Phase II of the Project.

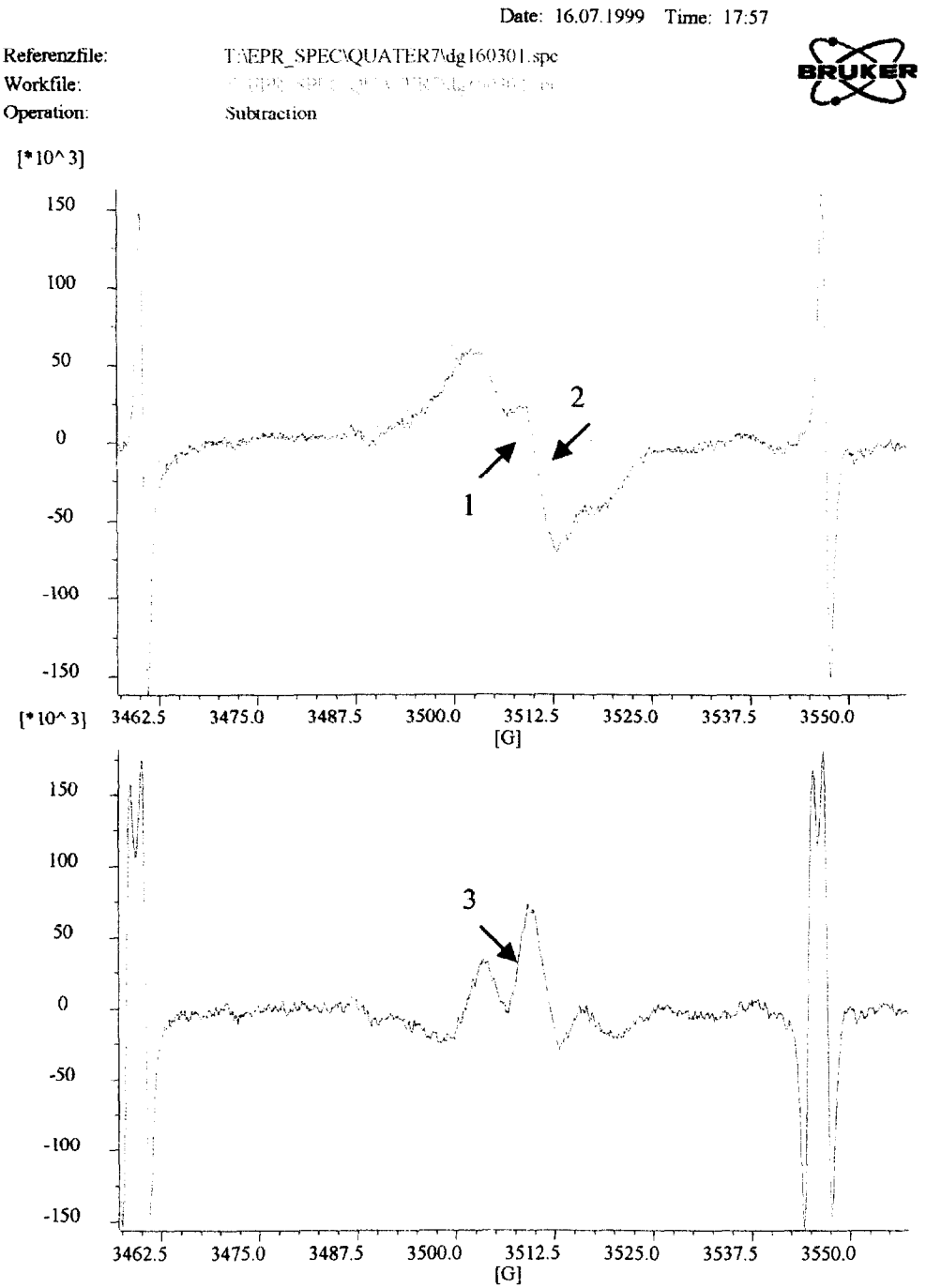


Figure A3.7 Spectra of a sample exposed by 0.5 Gy.

1 – spectrum recorded without gaussmeter (values of magnetic field were obtained using Holl probe),

2 – spectrum with using gausmeter,

3 – the difference 1 and 2.

4. Test of upgrated computer part of the spectrometer

The previous spectrometer configuration had 1 MB operative memory. In fact, this meant that maximum number of memory "pages" available for spectrum saving consisted of 12 through 15 ones. It is necessary to remind that spectrometer memory is divided into 256 so-called pages, each of them can hold, in principle, one spectrum, maximal number of spectra, which can be located into spectrometer memory, is determined by the volume of latter. Such state leaded to some problems with attempts to do more routine the procedure of EPR measurements because only goniometer using requires recording of 10 different spectra, don't taking into account spectra of the empty resonator, native standard sample and some others. New processor board has 8 MB of memory. This lets to use all 256 memory pages, if necessary. In practice, this gives possibility to use the advantages of multi modality that is in the base of OS-9 spectrometer's system. For example, it is possible to evaluate the spectrum of the previous sample simultaneously with recording of the spectrum of new one etc.

The connection of spectrometer to SCRM's computer net gives new advantages concerning development and routine use of automatically working post-recording procedures of spectrum treatment. Such connection gives possibility to direct copy the spectra from the OS-9 system to MS-DOS format, which is understandable practically by all PCs, and carry out all spectrum manipulations, using possibilities of PCs.

5. Test of upgraded EPR dosimetry technique in the course of the first stage of interlaboratory intercomparison (together with the CAD, University of Utah).

Five different molars cut into two halves each were irradiated at IAEA (Dr. K.Mehta) in the dose range 0-1 Gy. Dose of each sample was reconstructed by six different ways: using three different spectrometer configurations (involving standard rectangular, cylindrical and dielectric resonators' configurations) and three different dosimetry techniques (including that without additional irradiation, with one additional irradiation by a high dose and two different microwave power techniques). Each sample was additionally irradiated with five laboratory doses. Thus, 360 spectra were recorded and analyzed.

The results obtained along with the nominal dose values are presented in Table A3.3, the values being given in terms of air kerma. Digits 1 and 2 in each sample number refer to the buccal and lingual parts of a tooth, respectively. Different configurations correspond to different types of microwave resonator. Three different techniques were as follows:

P1 and P2 is two different microwave power technique. The values of P1 and P2 were 1 and 10 mW respectively.

W/o addit. irrad. is the technique in which universal calibration curve is used in order to transfer EPR intensity to the dose (without additional irradiation).

One addit. irrad. is a developed variant of the previous case. In this technique radiation sensitivity of each sample is evaluated after one high dose irradiation (5 Gy).

Where possible, standard deviation $\pm \sigma$ is given for each dose value. In some cases (two last techniques) there are no errors because the necessary information was not available.

Basic configuration is configuration 1. As it can be seen from Table A3.3 for this configuration the dose values estimated for the lingual and buccal part of each tooth coincided within the experiment error. So, arithmetic mean of the buccal and lingual parts was taken as a dose value for each tooth on the whole. These values are given in Table A3.4 with relative errors.

Table A3.3 Doses reconstructed separately for buccal and lingual parts of each tooth using different EPR spectrometer configurations (columns 2-4) and different dosimetric techniques (column 5-7).

	Config. 1		Config. 2		Config. 3		P1 and P2		W/o addit. irrad.		One addit. irrad.	
Sample # / dose, mGy	D, mGy	±σ, mGy	D, mGy	±σ, mGy	D, mGy	±σ, mGy	D, mGy	±σ, mGy	D, mGy	±σ, mGy	D, mGy	±σ, mGy
141a-1 / 99	97	11	95	21	108	19	126	29	91	24	90	22
141a-2 / 99	99	20	105	37	102	15	155	14	100		109	
142a-1 / 147	157	22	165	46	156	25	220	47	153		173	
142a-2 / 147	129	32	136	23	152	22	223	31	159	30	156	27
143a-1 / 327	232	26	229	19	234	18	279	38	256		253	
143a-2 / 327	199	47	249	32	210	77	257	76	239	18	227	13
144a-1 / 410	334	59	294	51	286	47	322	48	316	29	332	22
144a-2 / 410	324	42	286	63	314	89	355	136	344		377	
145a-1 / 819	603	77	618	74	632	53	713	97	612	74	611	62
145a-2 / 819	621	109	651	88	734	36	714	65	688		664	

Table A3.4 Doses of the intercalibrated samples reconstructed according to the routine EPR dosimetry technique.

sample #	Dose, mGy	Errors, ±mGy
141a	98	16
142a	143	27
143a	216	37
144a	329	50
145a	612	93

The respective correlation dependence with nominal dose values is shown in Fig. A3.8. It can be seen that for the two samples with minimum doses which are the most significant for the epidemiological studies the coincidence is within 3%. For the samples with higher doses the

correlation is worth and deviations of EPR doses from the nominal values are within 20-34 %. In terms of the epidemiological requirements such errors are permissible; however, they are not understandable in comparison with the essentially less deviation values for the samples with low dose values. The main possible cause of such deviations is breaking down of the spectrometer microwave unit that occurred during intercomparison measurements. The smaller probable cause is sample irradiation with nominal doses at IAEA.

The matter is that during irradiation the effect of such significant factors as irradiation geometry, material of the phantom containing samples during irradiation, position of samples inside the phantom was not controlled. All these factors should be taken into account at the second stage of intercomparison where 10 samples were irradiated with unknown doses in the range 0-1 Gy at IAEA at the end of August. The samples have been sent to the partner laboratories for dose evaluation. The second stage of intercomparison will take few months for sample measurements.

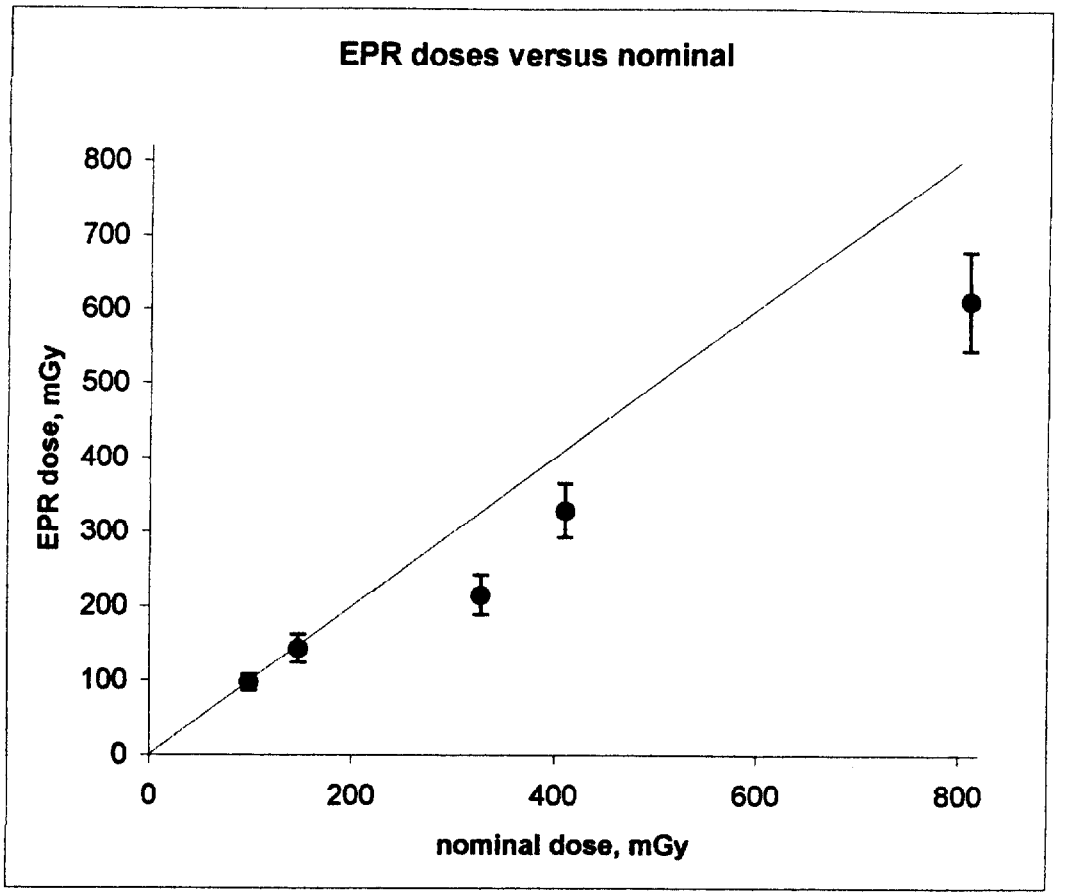


Figure A3.8 Correlation dependence of nominal dose values (x axis) and reconstructed by EPR method (y axis) for intercomparison samples.

APPENDIX 8

UPDATED EPR PROTOCOL

Appendix 8

EPR dosimetry protocol.

The EPR dosimetry technique with enamel used in SCRM is based on the following equation:

$$D_c = D_{ac} + D_{bg} + D_{x\text{-}ray} + D_{uv}, \quad (1)$$

where:

D_c – cumulative dose of enamel, is determined by EPR spectroscopy method,

D_{ac} – accidental component of dose, which is most interesting for application,

D_{bg} – component of dose from background environmental exposure, is determined by age of tooth and background gamma-dose rate and could be estimated approximately as 1 mGy per year,

$D_{x\text{-}ray}$ – dose from x-ray procedures,

D_{uv} – contribution to dose from ultraviolet (UV) exposure.

Essentially, reconstruction of accidental dose is two step process. First, cumulative dose of enamel must be assessed by means of EPR dosimetry. Second, non-accidental lifetime exposure should be evaluated and subtracted from the measured value.

The proposed technique was improved with respect to the most accurate determination of both cumulative dose and the life-time components. The doses for more than 300 liquidators were reconstructed.

Description of technique

The EPR dosimetry technique with enamel, used today in SCRM, could be described as the consecutive doing of the following procedures (Chumak *et al.*, 1997, 1999, Sholom et al., 1998a):

1. Separation of enamel from dentine and purification.
2. Estimation of initial dose for additional irradiation.
3. Additional irradiation of samples.
4. Recording and evaluation of EPR spectra.
5. Determination of the cumulative dose value and calculation of its accidental component according to equation (1).

1. Separation of enamel from dentine and purification

The essential part of SCRM's technique is a procedure of comprehensive purification of enamel from dentine and impurities. The main method of purification, which gives a good result for almost all samples, is a simple method of etching of big pieces of tooth in the NaOH solution at 60°C in an ultrasonic bath. Time of treatment and base concentration, which are applied (up to 80 hours and 2-3 N molar concentration), don't generate new centers in enamel. It was shown in special experiments. The solution is changed each 3 hours, the procedure is ended when color of solution stops to change. Then the sample is washed in distillated water in ultrasound bath, dried at 80°C and crushed into the grain range of 250-800 μm. After recording of an initial EPR spectrum, necessity of further purification of the sample is estimated. Experience shows that about 20 % of teeth required further purification. This purification is done in following way. Sample is crushed into fraction of 100-250 μm. Then, the procedure of NaOH treatment is repeated. After this about 15 % of teeth are good enough. The residual 5 % of teeth are cleaned with high-density liquid (sodium polytungstate with density of 3.1 g/cm^3). This procedure is ended by rinsing with distilled water in an ultrasonic bath.

2. Estimation of initial dose for additional irradiation

After an acceptable spectrum for a tooth is obtained, it is necessary to estimate the initial exposure dose. It will help us to estimate value of additional irradiation (Chumak et al., 1996). The initial exposure dose is calculated as a product of the initial dosimetric signal (g=2.0018) intensity and average radiation sensitivity value. A procedure of the initial dosimetric signal intensity determination is described in part 5 of this Protocol. The mean value of radiation sensitivity calculated for 300 measurements for different teeth was used as "average radiation sensitivity".

Depending on estimated initial dose value every tooth was assigned to one of the following groups:

1. With estimated dose close to 125 mGy.
2. With estimated dose close to 250 mGy.
3. With estimated dose close to 500 mGy.
4. With estimated dose close to 1 Gy.
5. With estimated dose close to 2 Gy.

3. Additional irradiation of samples

The sample should be irradiated 4 or 5 times using a gamma source (Chumak et al., 1996). The values of additional doses are defined by the group number.

The first dose increment for the first group is 125 mGy, and all others are 250 mGy. The values of dose increment for other groups are equal to the values which are used for group definition. For example, the increments for the second group will be 250 mGy, for the third group 500 mGy etc.

The sample is attached to an 8 mm plexiglas plate in such way that the plate is situated between the radiation source and the sample. The plate provides the secondary electron equilibrium at the sample attachment place. The ^{137}Cs high precision gamma source is used for sample irradiation. The samples are annealed for 2 hours at temperature of 90°C (Sholom et al., 1998**a**).

4. Recording and evaluation of EPR spectra.

The following parameters are used for acquisition of spectra. Central magnetic field 3480 G, field sweep 100 G, modulation frequency 100 kHz, modulation amplitude 4 G, time constant 40 ms, conversion time 20 ms, number of accumulation 60-120 (depends on the total dose of the sample). A 5-mm diameter tube is used as a holder of samples.

The important step in described EPR dosimetry technique is use of two subtractions when intensity of dosimetric signal is determined. First the signal of an empty tube recorded at the same parameter and during the same day that sample under study is subtracted. Then the standard spectrum of native signal (g=2.0045) of enamel is subtracted. Both subtractions are done after g-factor normalization. For the second subtraction the native standard signal is normalized in such way that maximum of the native signal of sample is equal to the maximum of native standard signal. Pure dosimetric signal remains after the normalized native standard signal is subtracted from the native signal of sample. In such way one reduces intensity of low-frequency noise up to values that are equivalent to doses of 20-30 mGy. It is real achievable accuracy at the determination of cumulative doses.

5. Determining of cumulative dose value and calculation of its accidental component according to equation (1).

The cumulative dose is determined as x-intersection of the regression line plotted through measured values of the dosimetric signal intensities for the initial and 4-5 times irradiated sample. Cumulative dose uncertainty consists of the dosimetric signal intensity measurement uncertainty and uncertainties of additional irradiation doses. The cumulative dose uncertainties were calculated according to methodology described in details in Chumak *et al.*, 1996.

An important part of EPR technique is dose conversion from cumulative to accidental value. There are at least two components of the cumulative dose that need special attention. First of them is a dose from UV exposure. Procedure of correct estimation of this component of dose is developed now, the first result is given in Sholom *et al.*, 1998b.

The next important component of cumulative dose is dose from x-ray diagnostic procedures. A method of this component estimation has been developed by Sholom *et al.*, 1997. This method is based on empirically determined values of dose from one x-ray examination (using the x-ray dental equipment typically used in Ukraine). These values are different for lingual and buccal sides of one tooth, and also depend on type of tooth (Sholom *et al.*, 1997).

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APPENDIX 9

FROM USED FOR THE IDENTIFICATION OF COLLECTED TEETH

Appendix 9

IDENTIFICATION OF THE EXTRACTED TOOTH

The full name or the stamp of the health center in which the extraction was performed.

2. ID number_____

3. Date of extraction_____

4. General information

1	Family name	
2	First name	
3	Patronymic name	
4	Date of birth	
5	Home or office phone number	
6	Home address	

5. Dates of participation in clean-up: from _____to_____

6. Duration of stay in 30 – km zone _____ days including 1986 _____

7. Place of work (organization in 30- km zone) during clean-up after Chernobyl accident

_____

8. Occupational exposure to radiation (including military service), when (year)		9. Information about X-ray examination of skull, jaws, teeth	
Yes	No	Yes (number)	No

10. Location of the tooth and reason of extraction:

À- paradontosis, R - radix, Rf- periodontitis, t- retentia.

8	7	6	5	4	3	2	1	1	2	3	4	5	6	7	8

11.Family name, first name and second name (personal stamp) of the dentist who extracted the tooth

_____

APPENDIX 10

FISH PROTOCOL

Appendix 10

FISH Procedures

VIZIS ***FISH*** PROCEDURE
(Using Superfrost VWR Slides)

DAY I

1. Place screwcap Coplin jars with:
   a. 2 x SSC – "pretreatment" solutions, and,
   b. Denature Solution, into 70-73°C water bath and let come to tempetature (~71°C) in the jar

2. Look at slide to be probed under phase objective and mark with a marking pen the furthermost left outside edge of area containing metaphases. (Slides should be a few days to 2-3 weeks old.)

3. Pretreat two slides at time 70-73°C in 2 x SSC for 10 min.

4. Transfer the pretreated slides to the Denature Solution for 5 min and at the same time begin another two slides in the 2 x SSC, repeating until all slides to be probed have been through the solutions.

5. **Immediately** following the 5 min denature treatment, transfer the slides in order for 2 min each into Coplin jars with 70%, 85% and 100% ethanol, agitating ` 3 cec at each step.

6. Slides are then allowed to air dry. **The following steps should be continued in reduced light.**

7.In a a small microcentrifuge tub, prepare "probe mix" for **two** 22x22mm^2 areas at a time as follows:

14 µl hybridization buffer
6 µl probe as prepared below*

* Vial of 100 µl probe containing chromosomes #1, #2, #4 (spectrum orange) is "prediluted" with 50 µl sterile distilled water and mixwd. This mixture should be stored at – 10°C to –20°C and thawed and remixed before each use.

8. The centrifuge tubes containing the 20 µl of probe mix should then be spun, vortexed, and spun again before denaturing.

9. Place two slides to be probed on hot plate (45°C) and float the centrifuge tube containing the probe mix (as in Step #8) in the little styrofoam "raft" especially prepared to hold the tube so the cone of the tube is in direct contact with 70-73°C water for five min.

10. Place 10 µl probe mix on each of the two slides carefully placing the drop near the center of the drop of cells to be probed. Using the etched mark as a guide, cower the "probe-mix drop" with a clean 22x22 mm^2 coverslip, avoiding bubbles if possible. (The hot tempereture will help rid drop of bubbles. Slide can be dropped slightly on hot plate to do this, and edge of coverslip can also be used to "pop" some of larger bubbles.) Allow liquid to spread under entire coverslip, before removing from hot plate.

11. Using Sanford's Rubber Cement loaded into a 5 ml syringe, seal the coverslip to the slide and set slide aside on the counter until sealant dries, but sealing is still effective.)

12. When all rubber cement is dry, place slides with coverslip upright into regular slide box (latched 100 slide) and place in the 37°C incubator for ` 48 hr.**

** As a matter of convenience, the slides may by left to hybridize 37°C over weekend (76 hr.) with no apparent detriment to slide.

DAY 2

Place 2 50 ml Coplin jars with 0.4 x SSC wash solutions into 70-73°C water bath and allow to come to temperature (~ 71°C) in the jar before continuing with wash procedure.

13. Very gently roll the rubber cement off the coverclip with the thumb and discard. Carefully push with forceps the coverslip off the edge, exposing a corner. Pull the coverslip up off the slide using the forceps and discard coverslip.

14. Immediately place slide in the 70-71°C 0.4 x SSC wash solution, agitating 1-3 seconds as doing so. Leave in solution for 2 min.

15. Transfer slides from o.4 x SSC wash tanks in same order to NP-40 (room temperature), wash for one min, also agitating briefly at this point, as vell.

16. Remove slides from NP-40, wipe the backs to remove soap film, drain slide briefly, and allow to drain and dry.

17. Place dried on ` 35°C plate (warm) and add DAPI (0.6 µg/ml in antifade) counterstain to slide. (15 µl covers nicely under a 24 x 40 mm coverslip .) The larger coverslip prevents oil from seeping underneath the slip and mixing with the counterstain when viewing slide microscopically.

18. The slide can be viewed by a fluorescent microscope (preferably 100 watt Hg bulb), immediately.

VYSIS
Solutions for Probe Procedure

2XSSC (for 250 ml. 20XSSC ***pH 5.3***)

Add 132 g 20XSSC to 400 ml H_2O and mix thoroughly. Adjust pH at room temperature with a pH meter to 5.3 using concentrated HCl and adjast to final volume of 500 ml. Filter throogh a 0.45 micron pore filtration unit. Store up to six months at room temperature.

2XSSC/0.1% NP (for 1 liter ***pH 7.5***)

Add 100 мл. 20XSSC (pH 5.3) to 850 ml. distilled water. Add 1.0 ml NP-40. Adjust pH to 7.5 with NaOH using a pH meter. Add water to bring final volume of the solution to 1 liter. Store up to six months at room temperature.

0.4XSSC Wash Solution (1 liter ***pH 7.5***)

Add 20 ml. 20XSSC (pH 5.3) to 950 ml. distilled water and mix thoroughly. Adjust pH to 7.5 with NaOH using a pH meter. Add water to bring final volume of the solution to 1 liter. Store up to six months at room temperature.

Denaturing Solution (70 ml. ***pH 7.5***)

Add 49 ml. Formamide, 7 ml. 20XSSC (pH 5.3) and 14 ml. distilled H_2O to a glass Coplin jar and mix thoroughly. Measure pH at room temperature using pH meter to verify pH 7.5. Use each batch of denaturant for seven days and then discard. Between periods of use, store at 4°C

Ethanol Wash Solution (70%)

Add 100 ml. C_2H_5OH (96%), 39,18 ml distilled H_2O

Ethanol Wash Solution (85%)

Add 100 ml. C_2H_5OH (96%), 13,37 ml distilled H_2O

2XSSC Pretreatment Solution (for 1 liter *pH 7.5*)

Make exactly as #2 without NP-40

DAPI Solution + Antifade

Stock: Conc=100 µg/ml in bottled distilled (sterile) H_2O
1 mg DAPI /10 ml
or, 0,1 mg DAPI/ml. Store at –20°C. Make fresh every 2-3 mos.
Working: Conc=0.6 µg/ml
Add 12 µl stock to to 2 ml antifade
Mix DAPI in antifade well. (May keep in lab. Freezer – 10°C or –20°C for one week for use on probed slides.)

APPENDIX 11

ADR PROTOCOL

Appendix 11

ADR protocol

1. Theoretical principles.

The underlying theoretical principle of the procedure of analytical dose reconstruction (ADR) is the consideration of external exposure doses and associated values as fuzzy quantities, i.e. quantities that are formed under the effect of factors of both statistic and substantially non-statistic (subjective) nature. Such an approach founds more and more wide use in radiation safety field. The first attempt to apply fuzzy set theory to assessment of doses was done in a work [Volkov 1989]. Authors have given an example of thyroid dose calculation under constant release of radioactive iodine-131 into environment. As it is demonstrated by Mishiwari 1988, the use of the fuzzy set theory is more acceptable in analysis of uncertainty of "dose-effect" relationships under emergency conditions than the probability theory that could be applied to repeating events only. This approach was applied in [Mishiwary 1984] considering human factors in accident.

Necessity of application of the fuzzy sets to retrospective dose reconstruction was demonstrated in [redacted]. It is well known that at early stage of cleanup the personnel of ChNPP as well as other groups of liquidators worked without personal dosimeters. Data on instrumental doses at some other period are lost. Nevertheless, there are files containing the information on professional route for most of early liquidators (so-called "route lists"). The method of analytical dose reconstruction uses the data from route lists and the information on radiation fields corresponding to the routs.

According to this procedure, retrospective dose evaluation for each liquidator should be performed in two stages:

1) Expert assessment of primary data on exposure levels based on a filled out questionnaire (see Appendix 2) and a liquidator's route list (see Kryuchkov 1996). At this stage, an expert splits the route list into a set of "episodes" corresponding to completed phases of work. Then, each episode is divided into separate "frames", i.e. time intervals during which dose rates could be considered as constant.

2) Retrospective dose reconstruction itself. At this stage, an individual dose is evaluated using data on dose rates on a route and derives a certain upper estimation M of route dose. Then, this upper estimation should be modified with known coefficients to give the expected value and two bounds that dose cannot overrun from the expert's point of view.

In order to explain theoretical aspects of this procedure (Kryuchkov 1996), let us consider a group of liquidators who took part in two episodes. Let D_{1i} and D_{2i} be doses of the i-th liquidator in these episodes. To treat doses in the framework of statistical methods we should consider D_1 and D_2 as random parameters D_{1i} and D_{2i} as their i-th realization. However, there are specific factors reflecting personal features of each liquidator that could affect individual dose, thus varying dose distributions of subsamples due to uncertainty of substantially fuzzy (non-statistical) nature. It was shown [redacted] that absorbed doses should be considered as fuzzy quantities with the use of the most conservative addition rule. The author introduces a membership function $f(D)$ of log-normal shape for the dose absorbed on a route (see Fig.A7.1). This function is a fuzzy analogue of a probability density function. Its maximum value is equal to 1 and corresponds to the most "expected" (100% possible) dose from the expert's point of view. The values where the membership function equals 0.5 correspond to maximum and minimum

doses by 50% criterion. As a result of rather cumbersome computations the author derives equations that associate these dose with the above estimation M made with use of maps of radiation fields in a route.

2. Basic principles of expert data evaluation

1. Retrospective assessment of the dose in case of external gamma exposure is performed by a group of experts consisting of at least three persons from the officially adopted lists of experts.
2. The experts consider the route list and questionnaire filled out by a liquidator.
3. In course of interviewing a liquidator, the expert specifies the information concerning episodes and frames of the route as presented in documents and obtained from other sources.
4. The expert has the right to request additional information on any episode or frame with the purpose to have complete information necessary for objective retrospective assessment of the exposure dose.
5. Calculations are performed with use of unified verified smoothed (interpolated) data about dose rates and verified route lists approved by Scientific-Production Association ChNPP or Dosimetric Control Administration of Scientific-Production Association "Pripyat".

3. Calculation algorithm

1. A route list is split into episodes by the unique way.
2. Each episode is divided into frames, i.e. time intervals during which dose rates could be consider as constant. The frame duration is determined as the median of evaluations of three independent experts.
3. In each frame dose rate is determined by maps of radiation conditions.
4. For each episode an upper Darboux sum is calculated, that is the products of the maximum dose rate in a frame and the frame duration are summed over all frames.
5. Summation of doses over all episodes yields into the upper Darboux sum M over the whole route.
6. The following values could be considered as retrospective dose assessments:

- first, the root of the equation $f(D)=1$, that is expected (100% possible) absorbed dose

$$D^{f=1} = M \exp(-1.5 \ln^2(\beta_g)) \qquad (1)$$

where β_g is the tabulated function of period after the accident (Table A7.1),

- second, roots of the equation $f(D)=0.5$ (see.Fig. A7.1), i.e. the maximum and minimum possible doses by 50% criterion

$$D_{\pm}^{f=0.5} = M \exp[-1.5 \ln^2(\beta_g) \pm \ln(\beta_g)\sqrt{2 \ln 2}] \qquad (2)$$

Table A7.1

The standardized values of β_g parameter

Month 1986	April-May	June	July	August
β_g	2.07	2.03	1.98	1.94
Month 1986	September	October	November	December
β_g	1.89	1.85	1.81	1.76

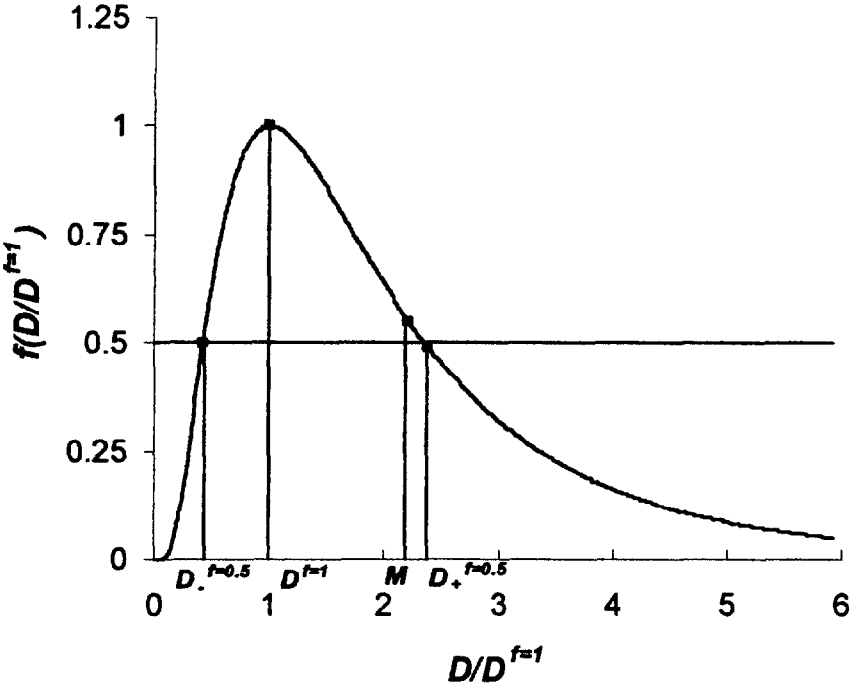

Fig.A7.1. The membership function of the dose in case of gamma external exposure is shown in dimensionless coordinates $D/D^{f=1}$ normalized by the expected dose value $D^{f=1}$. Here $D_{\pm}{}^{f=0.5}$ are the maximum and minimum dose values by 50% criterion, M is the expert evaluation of the maximum dose over a route (the upper Darboux sum M).

The values of the expected absorbed dose (1) as well as the maximum and minimum doses (2) could be explicitly expressed through the absorbed dose M calculated by a route list. These rather cumbersome expressions can be presented as M multiplied by the following factors

$$D^{f=1} = \gamma^{f=1} M; \qquad (3)$$

$$D_{\pm}{}^{f=0.5} = \gamma_{\pm}{}^{f=0.5} M \qquad (4)$$

The maximum and minimum possible doses by 50% criterion determine the upper and lower boundaries of the possible dose interval, while the expected absorbed dose is the most confident

dose ("best guess") evaluation. Taking into account the given values of the parameter β_g at certain periods after the accident, the coefficients of conversion from the rout dose to the doses (3) and (4) can be presented in the form of Table A7.2:

Table A7.2

Factors for conversion from upper Darboux sum (parameter M) to meaningful dosimetric values

Month 1986	April-May	June	July	August
$\gamma^{f=1}$	0.452	0.471	0.496	0.517
$\gamma_+^{f=0.5}$	1.065	1.085	1.109	1.129
$\gamma_-^{f=0.5}$	0.192	0.205	0.222	0.237
Month 1986	September	October	November	December
$\gamma^{f=1}$	0.544	0.566	0.589	0.618
$\gamma_+^{f=0.5}$	1.152	1.168	1.185	1.203
$\gamma_-^{f=0.5}$	0.257	0.275	0.293	0.318

Conclusions.

The main result of the assessment by this procedure is the determination of the expected dose (100% possible value in the expert opinion) and the interval of 50% determinacy of the dose (the upper and lower possible values of 50% reliability). Performing this task we tried to ascertain to what extent the experts could affected the result of dose reconstruction. An experienced expert can easily divide a route into episodes and frames, evaluate their duration and determine corresponding dose rates for those time intervals, especially in such cases as passage over a standard route. The basic discrepancies between expert evaluations occur in case of persons being in fields of inhomogeneous exposure. Analyzing the division of a route in separate episodes and frames by three experts we can obtain three different estimations of the maximum route dose, then evaluate the expected, maximum and minimum doses and determine overlap of the three estimations.

Analysis of ADR application to dose reconstruction for 20 workers.

In reality, an experienced expert divides a route into episodes and frames, evaluate their duration and determine corresponding dose rates for those time intervals. Then, by multiplying these parameters, the expert calculates a maximum possible dose on the route (which should be multiplied then by a factor of about 0.5 in order to obtain the most expected dose value). In order to test variations caused by the difference in evaluation by experts, three independent practitioners were asked to analyze route lists and conduct separate dose assessments. Despite the predictions that the discrepancies between the experts' estimates will occur in case of person's

service in non-uniform radiation fields, no discrepancies are found in such cases - the estimates coincide.

It turned out that practitioners are not aware on details of fuzzy set approach. Though, composing a detailed route list, an expert takes into account only authorized documents testifying liquidator's participation in clean-up, to calculate the contribution to the ADR dose the expert usually uses a certain approved list of standard episodes with known (pre-calculated) doses for them. This list was revised several times and gives rise to serious doubts from the point of view of one of the contacted experts. Most probably, doses in case of moving through areas of strongly non-uniform dose rates, for example, the pedestrian passage from Pripyat to ABK-1 (administrative-utility building) through ORU-750 (electric distribution substation) are overestimated. Nevertheless, experts were forced to use in their calculations those overestimated doses according to the officially approved list. So, they simply sum up pre-calculated standard episode values and evaluate manually doses related to rather unique episodes.

Hence, the error is determined by the estimation procedure and precision of the instrumental dose estimation.

To make a proper comparison of ADR with EPR for 20 selected workers it was necessary to select different components of dose for each of them. Certainly, lifetime dose of each individual consists of routinely monitored occupational dose and the dose evaluated retrospectively by ADR (for the period when monitoring data was missing). Therefore, in order to provide comparison with EPR (reflecting whole lifetime dose) the monitoring component of the individual dose that includes an occupational dose received before the accident and results of instrumental monitoring after the accident was isolated. Then typical components of the ADR calculations were identified as:

- work in 1986,
- Prypyat (residence, evacuation, and contaminated clothes),
- outside Pripyat, and
- en route (usually movement between Prypyat and the industrial site).

The last three components are accident-related and correspond to the period of April-May 1986. The results of comparison for 20 selected persons are shown as a bar chart in Fig.A7.1. Each case is presented by the set of two columns: EPR (crosshatch) and ADR (multi-component). Obviously, these components have substantially different uncertainty: for instrumental dose it is about 30-40%, the geometric standard deviation for the dose assessment based on above fuzzy technique was found to be ca. 2.3. En route dose in the most doubtful cases provides very significant and unjustified contribution to the ADR dose. Moreover, according to one of the experts, en route doses should be by the order of magnitude less than those indicated in the list of standard episodes reducing to a third the dose estimation.

The case A4 in Fig.A7 attracts special interest since it presents the estimation of dose made by one of the expert for himself (from his own assessments of doses for standard episodes). It could be seen that in spite of blind calculation the ADR estimation is rather close to the EPR value.

Method of direct expert assessment (DEA)

The idea to use the IARC questionnaire for analogue of ADR dose estimation arose in the course of testing SEAD method. The simplified method of dose calculation was named method of direct

expert assessment (DEA). Practically speaking, the experts try to simulate a virtual route list by consideration of the IARC questionnaire that was filled out in interview of a liquidator and to apply ADR method to make a dose assessment.

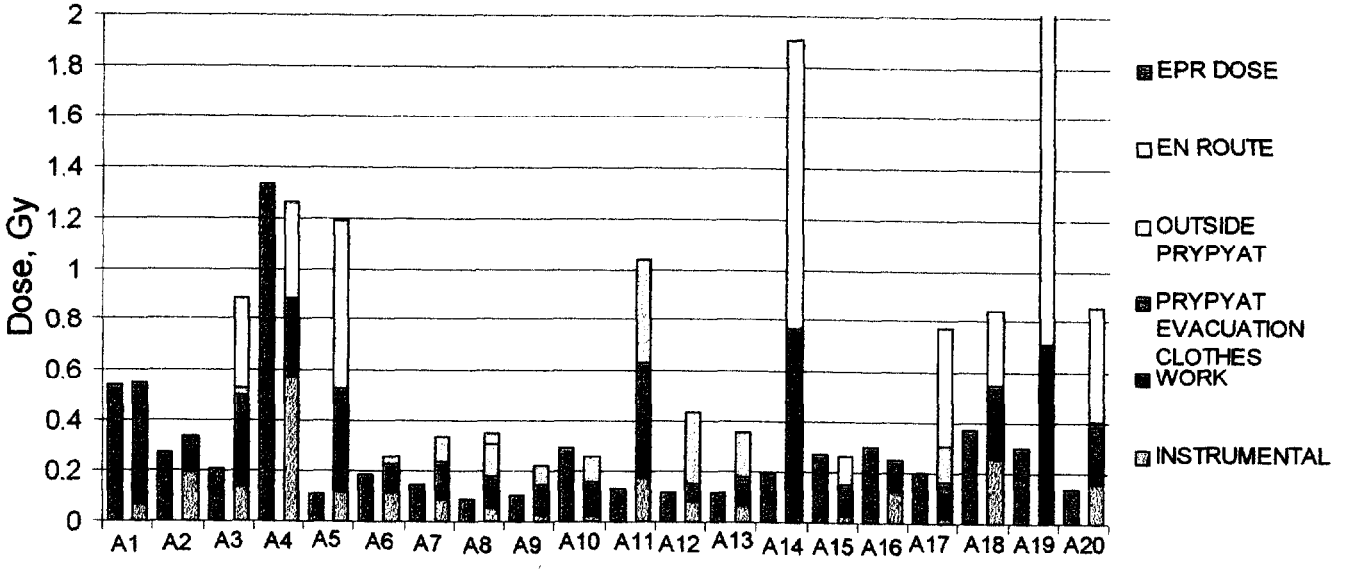

Fig A7.1. Comparison of ADR and EPR doses for 20 ChNPP staff members.

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APPENDIX 12

SEAD PROTOCOL

Appendix 12

Description of the SEAD method

Analysis of the national Registries showed that the doses are known not for all liquidators and that some of the doses given in the Registries require verification. As methods of biological dosimetry are not reliable and very expensive it was decided to try to develop a new method. We named this method Soft Expert Assessment Dose (SEAD) method.
As it is seen from the name of the method it is based on expert assessments of people and their circumstances. It is "soft" as the expert does not try to select some concrete variants he simply rejects those variants which with which he disagrees. The second meaning of the term "soft" in the methods name is caused by use of a special mathematical technique called "soft calculations".

8.1. Principal concepts of the SEAD method.

The principal idea of the SEAD method is to decrease uncertainty in the liquidator's individual dose assessment with the help of information obtained by interviewing him. Precision of results depends upon quality and quantity of the collected information. Thus it not possible to estimate the SEAD method general uncertainty.
One can estimate the initial uncertainty of the individual dose value. One can use the value of entropy S_H of the individual dose distribution for all liquidator groups working in 1986, 1987 as a measure initial uncertainty:

$$S_H = -\int_0^\infty p_H(D) \ln p_H(D) dD$$

here $p_H(D)$ is distribution function of the integral dose distribution for all liquidator groups in 1986, 1987.
According to Shennon, if one obtained information I than the final value of entropy S_K will be:

$$S_K = S_H - I.$$

The final expression is very general and it is valid when initial and final entropy are those for liquidator's dose distributions. In this case according to [Novicky and Zograf, 1991] the dose approximation error Δ will be defined by the following expression:

$$\Delta_D = \frac{1}{2}\exp(S_K) = \frac{1}{2}\exp(S_H - I)$$

The value S_K can be described as:

$$S_K = -\int_0^\infty p_K(D) \ln p_K(D) dD$$

here $p_K(D)$ is a final distribution function for values of the liquidator's individual dose, assessed by SEAD method. the final distribution $p_K(D)$ has not only less uncertainty compared to distribution $p_H(D)$, but it has less standard deviation i.e. less dose dispersion compared to the initial distribution $p_H(D)$.

An expert uses obtained information to reduce entropy of the individual dose distribution in two steps.

On the first step the expert decides to which group the given liquidator belongs. After that the dose assessment uncertainty will be defined not by the integral dose distribution for the whole set of liquidators, but by the distribution which describes only the selected group of participants of the clean up work at the ChNPP. Figure 5 illustrates how such a step essentially reduces the uncertainty.

On the second step the expert decides a rank of the considered liquidator, which is his place in the ordered along the dose increase liquidators set from the considered group of liquidators.

Then an equation is solved which has the same appearance for all groups of liquidators, but has different parameter values for different groups of liquidators.

8.2 Group, localization, and scaling factors.

Information from liquidator to interviewer and from interviewer to expert is transferred in the verbal form. Thus the expert has to transfer the verbal descriptions to the interval doses assessments. This transfer is implemented when the expert defines three quantitative characteristics that in SEAD method are named group, localization, and scale factors.

Group factor describes belonging of the liquidator to the definite group (to the definite structure which has a concrete problem to solve as a part of clean up work in ChNPP). In fact it defines the dose diapason which the considered person could obtain.

Localization factor expresses relation between the individual dose and a median dose value for the whole group to which the considered liquidator belongs.

Scaling factor indicates to what extent the considered liquidator can influence value of his officially registered dose.

Of all the factors only scaling factor is a quantitative one. All other factors are qualitative ones.

As it is known [Yadov, 1987], every quantitative and qualitative value is characterized by their scale of measurements and empirical indicators. An indicator is a well distinctive mark of the measured feature. As for measurement scale, there are the following scale types:

- a nominal scale (non ordered scale of names),
- partially ordered scale of names,
- ordinal (rang) scale,
- interval scale (a scale of equal intervals),
- an ideal or absolute scale (a scale of proportional assessments).

The two last scales are numbered scales. Irradiation doses as well as other physical values with a dimension can be described by scales with equal intervals.

"Group factor" is the first quantitative characteristics which an expert has to assign has a nominal scale. And the very names of liquidator groups (such as: time of the work in the 30 km zone begin, organization that sent liquidator to the 3 km zone, method of work in the 30 km zone: in shifts, or mission) are evident indicators. It is reported extensively about 17 groups of liquidators in the first part of this report.

The second quantitative characteristic in SEAD method described as "localization factor" has a rang scale. It has 12 indicators: date of work begin, duration of work, unit in which the liquidator worked, what kind of work he did, main and the most extreme working zone, attitude to the given job, personnel category, patronality (?), attitude to the radiation action, behavior variability based on the person's temperament and on direct expert assessment. The first six indicators in the list define working condition of the liquidator in the 30 km zone. Indicators from 8 to 11 define the person's disposition i.e. different consumption-motivational structures of the individual which somehow influenced his actions during work in the 30 km zone. The indicator "personnel category" has mixed personnel-situational character. The last indicator reflects expert's intuitive understanding of the radiational rang of the liquidator.

Indicators and radiational ranges are considered in SEAD method not as random but as "fuzzy" numbers. Such an exchange gives some advantages. But before we shall discuss these advantages it is necessary to say a few words about the very theory of fuzzy numbers.

Every measurement result (physical or "qualimetric") has two types of errors: random and systematic. Usually error analysis is limited by random errors. as for the systematic errors they are analyzed when experts discuss methodological principals of measurements collection. the probability theory is an adequate mathematical apparatus for random errors estimation. The theory of fuzzy sets (or it's subset – the theory of fuzzy numbers) can be used to estimate the systematic errors. One of the problems of so called soft calculations is the problem of addition of two values, one of which is random and another fuzzy. In real life one of the errors is essentially higher than another, then the problem of two uncertainties with the principal different nature summation has no meaning. It is supposed in the SEAD method that the systematic error plays principal role in estimation of values of the radiation rang indicators.

Transition from the probability theory to fuzzy sets theory gives the following advantages:

- the mathematical apparatus is adequate to the nature of uncertainties,
- one can use "soft" assessment of the radiation rang indicators values, according to which all indicator's values are accepted that are not rejected by the expert,
- there is no need in numerous unfounded hypothesis that are connected with the probabolistic approach.

Scaling factor is a dimensionless number and has an absolute scale. It has three indicators: individual coefficient of an official allowed dose modification, possibility of voluntary overexposure, and direct assessment of an expert. As a rule this indicator was equal to unity. Only very small number of liquidators had possibility and necessity to change their officially registered dose.

Number and content of indicators for scaling and localization factors was determined empirically after numerous discussions with dosimetry experts who had essential

experience in clean up work at ChNPP. It was decided to combine numerous indicators into two groups: factors of localization and scaling.
SEAD uses procedure of many indexes unification into single indicator that is often used in psychological testing or social questioning . This procedure consisted in collection of expert assessments based on a few nominal scales with consequent summation of them. Such summation was originally suggested by Laikert and was named "cafeteria" (as it was like a collection of courses in menu with calculation of the final lunch price).The summation result gives assessment of localization factor. Thus, localization factor is nothing else but a radiational rang of a liquidator. With the help of localization factor it is possible to regularize al liquidators from the same group according to the extent of their irradiation.
It is necessary to remember that in general intervals on the rang scale are not equal, thus ranges define order. And manipulations with number are manipulations with rangs, but not with doses. For example, if four liquidators have the following values of localization factors: 3, 5, 15, and 17. In general it does not mean that doses difference between the second and the first liquidators is equal to the dose difference between the forth and third liquidators. But there is some relation between the rang scale of localization factor and the proportional scale of individual doses. This relation is established by the transformation rule from the rang to the individual dose. SEAD method has such a rule for all 17 groups of liquidators. This rule is described in section 3.3.
Graininess of the different indicators scale is equal to 5 in the SEAD method. Such a crude enough scale provides high reliability of the value identification by an expert. Besides it provides acceptable precision of the sum index value for the localization factor, as a sum of 12 indicators gives 49 values for localization factor. In such a way the negative effect of the rude partial indicators quantification is reduced.

8.3 Transition from the localization factor to the absorbed dose.

There are the most important limitations which are necessary when one transfers from quantitative to qualitative markers in quantitative expressions [Yadov, 1987]:

- adequacy of quantitative markers fixed by different scales in the framework of a problem solution. Mixing of different measurement gauges in an investigation leads to lost of the better scales advantages.
- it is supposed that the values fixed by the given scales are normally distributed.

Let us check whether these requirements are valid for SEAD method.
As was stated earlier, three factors define the liquidator dose. The scaling factor is a dimensionless marker and has an absolute scale. It can not worsen the absorbed dose value as it has more precise scale. As for two other factors – group and localization – they have in fact less precise scales – nominal and rang scales, and they can worsen the dose value D for a liquidator. Besides, all 17 groups of liquidators have very asymmetric empiric dose distributions. Thus both mentioned above requirements for transition from qualitative to quantitative markers are not valid. But there is a technique that can help to achieve reliance with the formulated above requirements.
It can be achieved if for every liquidator groups we find such an absorbed dose transformation that the new variable u will be distributed normally n(0,1). At that the transformation type will be the same for all groups, but the transformation parameters will be in general different. In fact, if such a transformation exists, the group differences

will be removed as all of them will be normally distributed n(0,1). Besides, it will be possible to tie rang of localization factor with a value of variable u that will not depend upon groups of liquidators. At last the u value will be normally distributed and the second requirements formulated in the beginning of this section will be valid. It is obvious, that after transition from a rang value to variable u was done it will be necessary to transfer u to the dose value with the help of inverse transformation different for every group.
Figure 5 illustrates this idea. Different (exemplar) distributions are shown in Figure 5 that are localized in different dose diapasons. With different transformations $f_i(D)$ these distributions are transformed to a single distribution and radiation ranks (the vertical lines) are hard and fast tied to this distribution (concrete values of u). Then with the help of an inverse transformation $f_i^{-1}(u)$ it will be returned to the variable D space. after that the rank localization character will be different for different groups and hard and fast tied to the dose values.

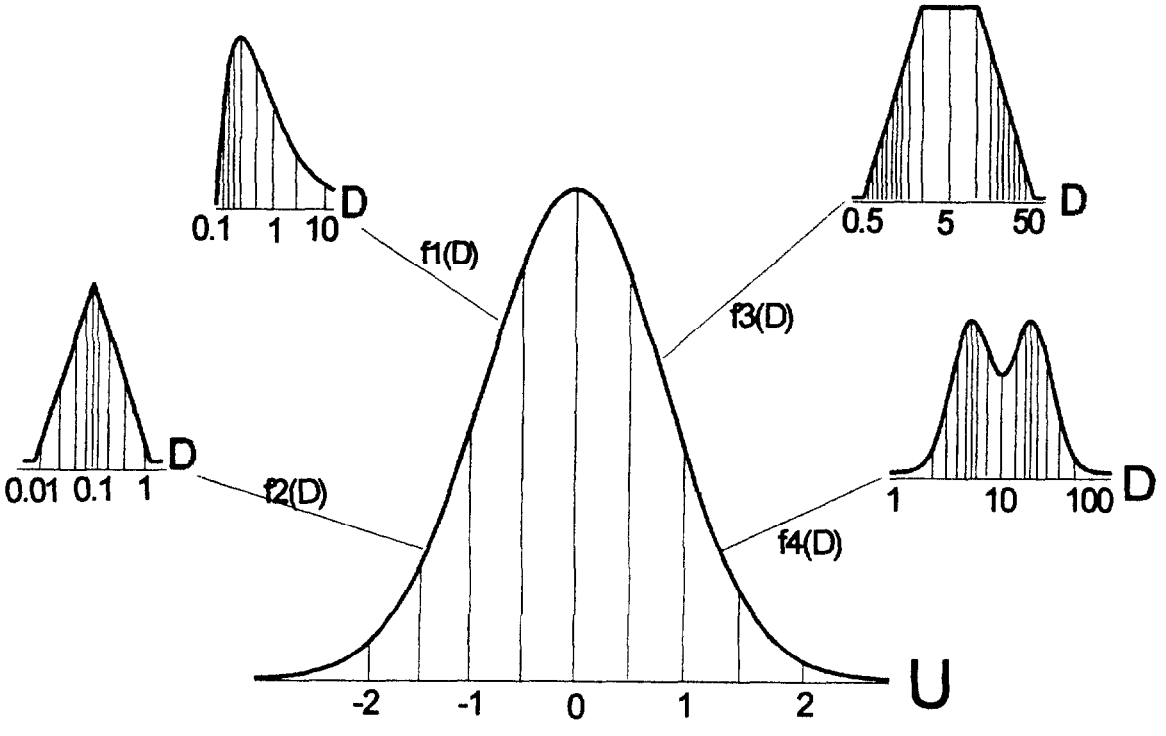

Fig. 8.1. Transformation to the universal radiational ranks.

We used to transform empirical dose distributions to the normal distribution n(0,1) the following transformations:

1. hybridlognormal transformation of the dose D to the value H:

$$H=Hyb_{\rho}D=\ln(\rho D)+\rho D,$$

2. then value H was standardized:

$$h=(H-<H>)/\sigma_H\,, \qquad (1)$$

3. then value h was raised to a power:

$$U=\mathrm{sign}(h)\cdot |h|^{\alpha}, \qquad (2)$$

4. and value U was standardized

$$u=(U-<U>)/\sigma_U\,. \qquad (3)$$

It is possible to express the normally distributed n(0,1) u value as a function of individual dose D:

$$u=\frac{\{\frac{Hyb_{\rho}D-<H>}{\sigma_H}\}^{\alpha}-<H_{\alpha}>}{\sigma_{\alpha}} \qquad (4)$$

For real data $<H_\alpha>$ value is always close to zero and it can be neglected. The value $\sigma_\alpha=f(\alpha)$ it is well approximated by a linear-square dependence from α:

$$f(\alpha)=0.476+0.671\cdot\alpha-0.146\cdot\alpha^2 \qquad (5)$$

Thus, expression (4) can be transformed into:

$$u=\frac{\left\{\frac{Hyb_{\rho}D-<H>}{\sigma_H}\right\}^{\alpha}}{f(\alpha)}$$

All empirical distributions used for development of the SEAD method had the same defect. All these distributions were mixtures of a continuous physically reasonable dose distribution and a discrete artifact distribution, caused by the dose values rounding or by application of calculations. The working group on dosimetry for leukemia projects on one of its meeting (Lyon, September 21-22, 1998) decided that these peaks have to be removed by peaks dissolution.

The peaks dissolution procedure was as follows. Every dose value from a peak was multiplied by a random number r with lognormal distribution with parameters μ=-0.14 и β_g=1.7. These parameters guarantee mean values of r to be equal to 1. In result the dissolved peak values in average coincide with the peak value. If one uses instead of peaks dissolution procedure peaks removal, then if there are comparatively many "peaked" values it will result in an inappropriate shift of dose distributions to the higher values domain.

The common methods of visual analysis of empirical histograms and application of parametric and non parametric accordance methods was in this case ineffective, because it was necessary simultaneously analyze many distributions and their parameters varied in a wide range. We used a special method of a dose distribution form analysis. According to the method every distribution was considered as a point in a "phase space" where entropy coefficient K and contrexcess Q are coordinates.
The value Q is defined by the forth central moment of distribution μ_4, and the standard deviation σ of a random value x as:

$$Q = \sqrt{\frac{\sigma^4}{\mu_4}}$$

and is called contrexcess of an distribution. For different distributions Q can have different values, from 0 for Cochy distribution ($p(x) = \frac{a}{\pi(a^2 + x^2)}$) to 1 for a binary distribution ($p(x) = \frac{1}{2}(\delta(x-a) + \delta(x+a))$).
The entropy coefficient K is defined as:

$$K = \frac{\exp(H^*)}{2\sigma}$$

here H* is so called differential entropy of an distribution. It can be calculated with the help of delta-entropy H(δ) of the distribution:

$$H^* = H(\delta) + \ln\delta,$$

here δ is histogram interval. The delta-entropy is defined as:

$$H(\delta) = \sum_{i=1}^{N} p_i \log p_i$$

here p_i is a frequency of a random value x hit into interval (x_i, x_{i+1}); $x_{i+1} - x_i = \delta$; and N is a number of intervals. For different distributions K can have values from 0 to 2.066 (for a normal distribution).
We managed to find for all 17 groups of liquidators to find such transformations of empirical distributions, that their transformed distributions were normal. Parameters of these transformations are given in Table 8.1.

Table 8.1. Values of parameters ρ_c, α_c, μ_c, and σ_c^* for different groups of liquidators.

Group factor (value of C-factor)	ρ_c	α_c	μ_c	σ_c
1	2	3	4	5
Accident witnesses	0.0056	1	-1.16	1.05
Early liquidators	0.026	1.03	-1.95	2.02
Personnel of ChNPP in 1986	0.0024	1	-4.40	1.12
Personnel of ChNPP in 1987	0.277	1	-0.769	1.12
Sent to ChNPP in 1986	0.019	1.06	-3.22	1.82
Sent to ChNPP in 1987	0	-	-0.41	0.55
Sent to the 30 km zone –1986	0.0001	1.25	-9.57	1.66
Sent to the 30 km zone–1987	0.0001	1.30	-10.2	1.28
Military liquidators and MIA in 1986	0.016	0.90	-1.32	0.77
Military liquidators and MIA in 1987	0.028	0.95	-1.39	0.88
Civilian personnel of US-605 in 1986	0.066	1.40	-1.29	2.12
Civilian personnel of US-605 in 1987	0.0192	1.60	-3.61	1.69
Military builders from US-605 in 1986	0.539	1.70	6.82	5.76
Military builders from US-605 in 1987	0.107	1.30	-0.60	2.05
"Combinat" personnel (1987)	0.593	0.85	-0.113	1.39
Belarusian liquidators (Gomel, 1986)	0.107	0.95	-0.089	1.51
Belarusian liquidators (Gomel, 1987)	0	-	0.26	0.347

Values of localization parameter φ_L (from now on let denote u as φ_L) and scaling parameter φ_S are defined by values localization and scaling factors.
After values of all 12 indicators for localization factor are summed up the result can be between 12 and 60, i.e. can have 49 values. the distribution of φ_L values can be represented by a histogram with 49 equally probable columns that means that the probability of a φ_L value to be one of the columns will be 1/49. It is accepted that the numerical values of φ_L correspond to the column number of such a histogram, and the column number is equal to the value of the radiational rank (localization factor value). Table 8 is used to transfer from the values of localization factor to the parameter of localization φ_L.

Table 8.2. Transfer from the localization factor values to the standardized value of φ_L.

L	φ_L	L	φ_L	L	φ_L
1	2	1	2	1	2
12	≤-2.0495	29	-0.3395	46	0.5655
13	-1.7435	30	-0.2860	47	0.6265
14	-1.5460	31	-0.2330	48	0.6900
15	-1.3955	32	-0.1805	49	0.7565
16	-1.2710	33	-0.1290	50	0.8265
17	-1.1640	34	-0.0775	51	0.9005
18	-1.0685	35	-0.0260	52	0.9800
19	-0.9820	36	0.0250	53	1.0665
20	-0.9025	37	0.0760	54	1.1615
21	-0.8280	38	0.1275	55	1.2685
22	-0.7580	39	0.1795	56	1.3925
23	-0.6915	40	0.2315	57	1.5425
24	-0.6275	41	0.2845	58	1.7385
25	-0.5665	42	0.3385	59	≤2.0405
26	-0.5075	43	0.3930	60	>2.0405
27	-0.4500	44	0.4490		
28	-0.3940	45	0.5060		

There are no special conditions for the parameter φ_S but that the general understanding that has not deviate far from unity. Values of the scaling factor are equal to the values of the scaling parameter φ_S.

Thus the liquidator's individual dose is defined as a solution for the following equation (***):

$$\mu_c + \sigma_c [f(\alpha_c) \cdot \varphi_L]^{1/\alpha_c} = \ln\left(\frac{\rho_c D}{\varphi_S}\right) + \frac{\rho_c D}{\varphi_S}$$

Parameters of individual dose distribution ρ_c, α_c, μ_c, and σ_c in expression (***) refer to such a group of liquidators to which the considered liquidator belonged. The values of these parameters are given in Table 8. Function $f(\alpha_c)$ is approximated by the following polynomial:

$$f(\alpha_c) = 0.476 + 0.671 \cdot \alpha_c - 0.146 \cdot \alpha_c^2$$

Methods of equation (***) solution with parameters being fuzzy numbers are given in section 3.4.

8.4 Algorithm of SEAD method.

Algorithm of SEAD method is fully described in report [ ]. Here we show main steps of the dose evaluation algorithm.

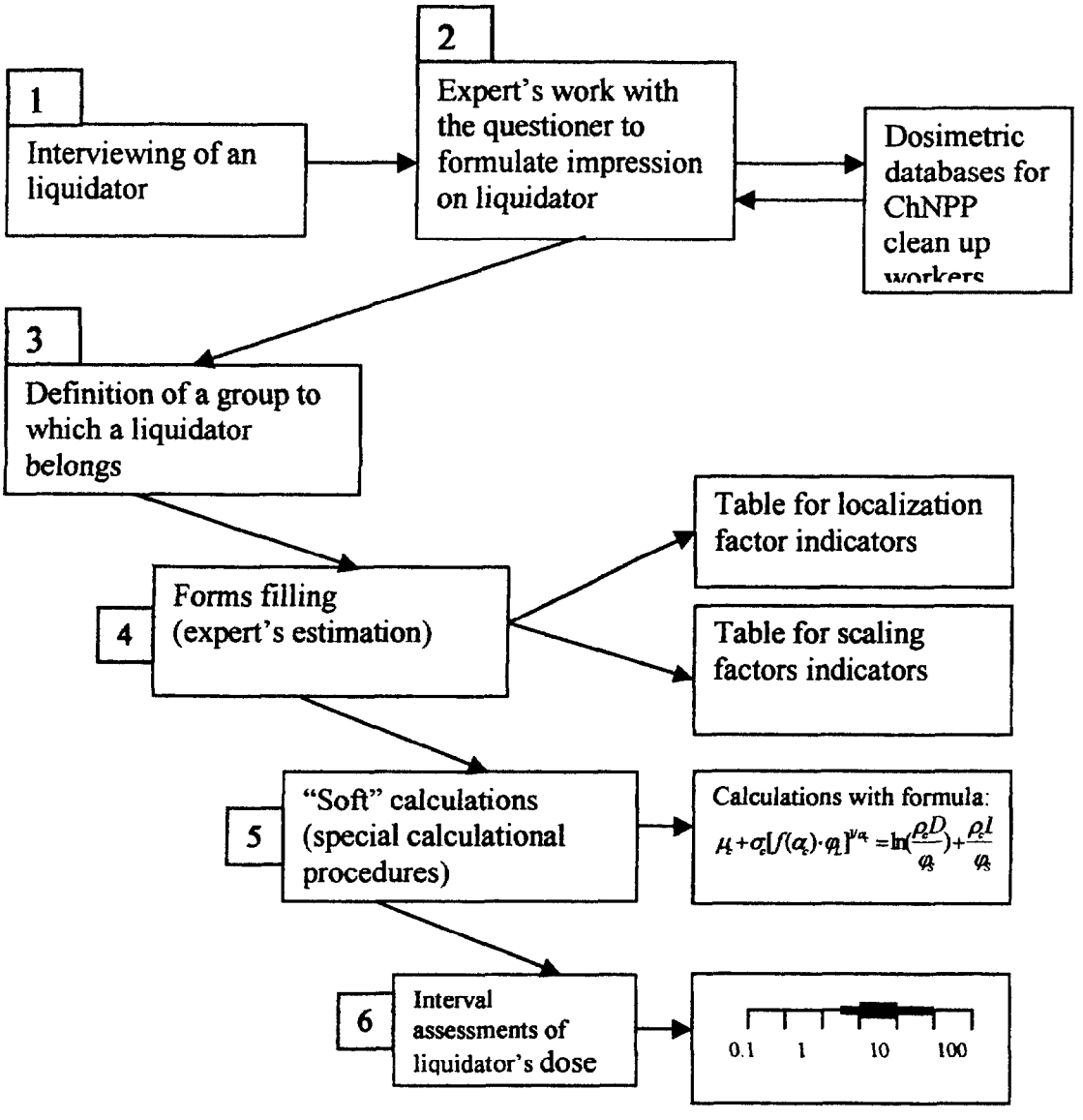

Fig. 8.2. Principal scheme of SEAD method.

The principal scheme of SEAD method is given on Figure 6. Strictly speaking the first step (interviewing of a liquidator) is not a part of SEAD method. Initial information about a liquidator can be obtained by other methods, for example by a non formal questioning of the liqudator by an expert. Nevertheless it is included in the scheme as it works exactly in this way in currently working leukemia project.

Then an expert works with the questioner. The expert needs to get a holistic impression about the character and working conditions of a liquidator. He has to understand the individual features of the person which can influence his attitude towards work in the 30 km zone. The questioner gives such a possibility to the expert. It contains answers to the open questions and comments to the answers, besides there are questions for the interviewer. We consider these questions to be a very important part of the whole interview. The interviewer is the only person who can describe non verbal behavior of the interviewee.
The expert has possibility to use information on liquidator individual doses which is collected in the existing databases and on dosimetric situation in working places.
Then the expert has to define to which of 17 groups the considered liquidator belongs. It is not a trivial procedure. Wrong decision may result in very grave errors. To reduce the probability of such errors there is a definite algorithm of a group selection and actions to verify this selection. All other steps are based on the group selection.
After that the expert fills tables for localization and scaling factors indicators. Examples of such filled tables are given in Tables 9 and 10. Numerical values given in the Tables 9 and 10 cells reflect assessments made by an expert in numerical scale of possibility that the qualitative value of the i-th indicator of the localization factor has a numerical value corresponding to the j-th column. The numerical values correspond to the following estimations of the probability extent for the considered qualitative values: 0 – "impossible", 0.25 – "very doubtful", 0.5 – "difficult to say", 0.75 – "probable", 1.0 – "of course".

Table 8.3. Assessment of localization factor indicators.

Localization factor indicators		Variants of qualitative values of localization factor indicators				
		Very low	Low	Compar-able with average	High	Very high
1		2	3	4	5	6
L_1	Beginning of clean up work	0	0	0	1	0
L_2	Duration of clean up work					
L_3	Unit with which the liquidator worked	1	1	1	1	1
L_4	*Speciality during clean up work*	0.1	0.3	1	0.6	0.2
L_5	Main working place during clean up	1	0	0	0	0.5
L_6	Extremal working place during clean up	0	0	0	0.7	0
L_7	Personnel class	0	0	0	0	0
L_8	Patronality (?)					
L_9	Attitude towards radiation action					
L_{10}	Attitude towards job					
L_{11}	Behavior variability based on liquidator's temperament					
L_{12}	Direct expert assessment					

*) Values in the shaded cells are designedly equal to 0.

Examples of possible rows in Tables 9 and 10 fillings are given in Table 9. Filling of the row "Beginning of clean up work" has very high certainty, while the row "Unit with which the liquidator worked" is almost completely uncertain. Filling of the row "Speciality during clean up work" illustrates typically fuzzy estimation of an indicator value. Assessment of the localization factor component "Main working place" is an example of an alternative estimation. Filling of the rows "Extremal working place" and "Attitude towards radiation action" shows an unacceptable approach to the forms filling – the maximal value in every row has to be equal to 1.

Table 8.4. Assessment of scaling factor indicators.

Scaling factor indicators		Variants of qualitative values of scaling factor indicators				
		Strong reduced	Reduced	Did not influence	Increased	Strong increased
1		2	3	4	5	6
S_1	Individual coefficient of official dose modification	0	0	1	0	0
S_2	Possibility of voluntary overexposure			1	0	0
S_3	Direct expert assessment	0	0	1	0	0

Every row in Tables 9 and 10 is considered as a representation of a fuzzy number which describes of i-th indicator of localization and scaling factors.
After that, indicators of localization factor are summed up[1], and for indicators of scaling factor geometric mean[2] is calculated according to the fuzzy numbers arithmetic rules.[1]
In result one will obtain values of the localization and scaling factors.
After that with the help of Table 8 one transfers fuzzy values of localization factor into equation (***) parameters and solve it. Solution of this equation is a fuzzy number as parameters of the equation are fuzzy numbers. Let us explain how it happens.
Equation (***) is solved many times with respect to the value D/φ_S for every non fuzzy value of the parameter φ_S. For example, if φ_L={0/0.10, 1/0.12, 0.5/0.15}, here number in front of «/» is a value of belonging function for the parameter value, given after the «/» operand, then equation (***) is solved three times for the parameter φ_L values equal to 0.10, 0.12, and 0.15. Three solutions of the equation (values of D/φ_S) correspond to the given non fuzzy values of parameter φ_L. It is considered that their belonging function is the same as was for non fuzzy values of parameter φ_L.

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[1] If A and B are two fuzzy numbers with belonging functions $\mu_A(a)$ and $\mu_B(b)$, then C=A+B if the belonging function of C is defined as:

$$\mu_C(c) = \max\{\min[\mu_A(a), \mu_B(b)]\}, \forall c = a + b$$

In this expression minimum is defined for all pairs a and b, which summed up to c, and maximum amongst all such minimums.

[2] If A and B are two fuzzy numbers with belonging functions $\mu_A(a)$ and $\mu_B(b)$, then $C = \sqrt{A \cdot B}$ provided that the belonging function of C is defined as:

$$\mu_C(c) = \max\{\min[\mu_A(a), \mu_B(b)]\}, \forall c = \sqrt{a \cdot b}$$

If $\varphi_S = 1$ (as a rule it is so), then the solution of equation (***) is found. Otherwise the dose value is calculated with the formula: $D=(D//\varphi_S)\cdot\varphi_S$. Thus, after solving the equation (***) we will get a fuzzy number D with a known belonging function $\mu(D)$. This function describes all uncertainties in the dose estimates the sources of which were in the initial questioner.

Then a fuzzu number D is transferred to an inteval dose assessment. The dose interval bounderies are defined on the values level $\mu(D)=0.5$ and $\mu(D)=1$. According to SEAD method, dose values from an interval with boudaries $\mu(D)=1$ means that the considered values could be received by considered liquidator. Doses from the dose interval $\mu(D)=0.5$ are such doses that according to the SEAD method can not be categorically denied.

APPENDIX 13

REFERENCES

Appendix 13

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